PHOTOVOTAIC SYSTEM MODELS IN SMALL COMMUNITIES

Worcester Polytechnic Institute

Interactive Qualifying Project

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1. ABSTRACT

As the price of conventional energy rises and the price of PV technology drops, it is inevitable that solar energy will become a feasible option for people throughout the world. Two proposed PV system models are examined and compared with the cost of conventional energy over the next twenty-five years: a case that involves individual PV system on every household and another case with a grid connected to a solar farm.

2. EXECUTIVE SUMMARY

In today's modernized and industrial world, energy is a necessity of everyday life. In the past few decades, the increased cost of energy has shocked the world's economy. With conventional energy prices soaring, many countries around the world are working together to find alternative energy sources that will substitute for them. Not to mention burning large amounts of oil and gas releases tons of carbon dioxide into the earth's atmosphere everyday, which is claimed to be the main cause of global warming. There are many fields of research in the world attempting to solve this energy problem. The most commonly known research includes solar energy and wind energy. Solar energy technology is the most widely used alternative energy resource in the world because sunlight is abundant and free of charge. Many countries around the globe are starting to emphasize the use of solar technology. Governments have carried out programs that will subsidize and give incentive for people to use solar energy, but the cost of building a solar energy system is still too expensive for most people.

With the increasing price of conventional energy and decreasing price of PV technology, building a solar panel system is becoming more feasible than ever. According to Hubbert's peak, the world's oil production rate will reach its peak around the year of 2001, which means the world had reached its maximum oil production capacity. The shortage of supply and the high demand for oil is the main cause of high-energy prices, as predicted by Hubbert's peak. Possible technological breakthroughs may improve the efficiency of photovoltaic (PV) modules, which could reduce the cost of building a PV system.

In this study, two PV systems are proposed for a small community. One system consists of individual PV system installed in every home, while the other system involves using a solar farm that supplies energy for the whole community. The costs of building both systems are investigated as well as the price that the community would pay for conventional energy over the next twenty years.

The grand total cost for building the solar farm and individual household is estimated to be about $472,865 and $14,470, respectively. If the safety factor were taken into account, the grand total cost would come out about $1 million for the solar farm and

$33,567 for individual case. In comparison, if the same community were to use conventional energy it would likely cost them between $397,000 and $428,000.

Fuel cells and quantum dot technology research may also be the answer to our future energy problems. Fuel cells are energy storage systems that allow more energy to be store comparing to batteries. Quantum dot technology will boost solar panel efficiency to almost 65%, which is a huge improvement compared to 16% with current technology. However, these two technologies are still in the development stage. Societies that support any types of research will help the world to reduce its reliance on the conventional energy resources. Many small areas around the world are already starting to use solar energy as their main energy source. These small communities are able to break free from their reliance on conventional resources, which results in a stable economy that is not affected by the price of conventional energy. Residents within these communities share their life together based on their religious or cultural beliefs. These communities may become self-sufficient and self-maintained using a PV system. These self-sufficient communities implement PV systems on a small scale, but if society put in extra effort to use alternative energy then the world will be a place with less pollution and would break away from the oil base economy system.

3. INTRODUCTION

3.1 – MOTIVATIONS FOR STUDYING PV SYSTEM

The group that conducted this study consisted of members from electrical and computer engineering, mechanical engineering, computer science, and biomedical engineering departments. Their interests and motivations in studying PV technology vary.

3.1.1 – Xu Lin

Energy is the most important resource in this world and also the backbone for human civilization. With the shortage of energy, it’s more important for us to find possible solutions to deal with this issue. As an ECE student, this project has led me into researching the solar panel, which could be the best type of alternative energy resource for the future. By using the skills I have accumulated over these past years in WPI, I am able to help design a virtual simple solar energy system to power individual residential houses. As a student, this is one of the best opportunities for me to do intense research in the field of alternative energy resources and helps solve real world problems.

3.1.2 – Calvin Mui

My motivation for this project consists of developing methods and suggestions to finding proper substitutes to current energy resources. The current energy resources consist of natural gas, coal, and petroleum. Eventually, these resources will vanish because of their scarcity. One of our goals for this project is to propose any suggestions or even solutions to finding effective substitutes to current conventional energy resources.

The relation between this project and my course of study at Worcester Polytechnic Institute consists of applying knowledge that is learned from courses such as Computer-aided Design, Kinematics of Mechanisms, and Statistics. This knowledge would be used to perform data analyses and solar energy technology up a visual model for the project. An engineer’s job is to find solutions from scratch or with the given resources and be able to give solutions to problems. Students can apply problem skills to solve real world problems.

3.1.3 – Minh Duong

Even though solar energy is not related to the biomedical field, it’s in my interest to gain knowledge of this remarkable technology. Like most other people around the globe, I used conventional resources due to its low price. I knew that these conventional resources such as oil and natural gas are limited around the world. The increased usage and cost of these resources could pose a problem in the future. Besides the increase in oil prices, the environment would be hostile for people to live in because of the increase in CO_2 emissions. What interests me most about solar energy is its environmentally friendly and abundant nature. I am even more amazed at the potential of using the PV technology anywhere where there is sunlight. This project would give me an insight of how much it costs to build the PV system and why it’s still not economically feasible for everyone yet.

3.1.4 – Jason Brooks

As an American citizen who uses vast amounts of energy in my everyday life, I feel that I should not remain ignorant to the growing problems associated with such energy consumption. Our society cannot use conventional energy resources forever, as there is a limited supply, and should discontinue their use as soon as possible. Solar energy has great potential to become the power source that will eventually replace conventional energy. I would like to know more, not only about where this technology is going, but also how feasible solar energy is to implement using today’s technology.

It’s likely that I will not use the knowledge of solar panels, intentional communities, or conventional energy trends that I will gain from this project. As a computer science major, this project will help me in data organizing and modeling skills.

3.1.5 – Team’s Motivation

Besides the motivations and interests from each individual team member, there are other aspects that motivated the team to study PV technology, which include its environmentally friendly nature, its declining costs, and its applications.

3.1.5.1 – Environmentally Friendly

Conventional energy sources can damage air, water, land and wildlife, as well as raise the levels of harmful radiation. Eventually renewable energy sources will replace the use of conventional energy sources and the environment will be less polluted. This is one of the reasons tax incentives may be put into place to assist in the implementation of clean renewable energy sources like solar energy if it is needed to compete economically. Using solar energy would eliminate all of these problems, with the exception of the insignificant pollution caused by the production of most solar energy technologies.

3.1.5.2 – Declining Costs

Energy shortage is the main problem for today's society, as the demand for oil grows faster than the supply; the law of supply and demand has driven the price of oil to record high. The rise in oil price had caused instability to the economy. In order to solve this energy shortage, many energy industries are eager to find another energy resource that can be a substitution for oil. Government officials are encouraging private industries to develop high efficiency solar panels to meet the energy demand. With large numbers of private industries working together to research new ways to produce high efficient solar panels with lower price tags. In the near future there will be a big drop in the cost for the solar panels. In addition, with high price of oil it will be more feasible to use solar energy systems than ever before.

3.1.5.3 – Applications

Currently, the use of solar technology is put to more use in many applications in people's daily lives. It has been used for commercial products such as calculators and digital watches as well as supplying power for grid companies. There are many different ideas that have been developed incorporating solar technology which include desalination, house heating systems, household appliances, satellites, telecommunications, transportations, and space exploration. With the advancement and use of solar energy, the promise of PV technology in the near future will soon be greater and will be more competitive in the market with other resources.

3.2 – CONVENTIONAL RESOURCES

3.2.1 – Availability

During the time period of 1850s-1990s, the world began to prosper through oil production. Oil production rates had been increasing better than any other time period. However, because human beings live in a world of limited resources, a part of our minds may fail to realize the word “limited.” Consequently, we will eventually have to live in a world where the resource of oil becomes extinct, which is inevitable and definitely poses a big problem. Looking into the future, we should plan ahead and find the best alternatives possible to come up with a solution to the problem of limited oil production.

Human beings have come up with several alternatives. These alternatives are: (1) keeping the worldwide economy stable in such a way that human beings would not lavishly waste resources, (2) coming up with new alternatives and resources which could hopefully lead to a proper substitute for oil production in terms of energy resources, and (3) have countries fight over the oil. The third solution can definitely be omitted since fighting over who gets whatever share of the oil could lead to negative drastic consequences such as war. The third alternative is possible but still does not solve the problem, especially if countries run out of their own oil supply from reserves. The second alternative is probably the best option since there is hope that oil production can be substituted with another technology that acts as a source of our energy supply. If the second alternative does not work, then it’s back to the first and the third alternative, which poses no solution as time progresses. Dr. M. King Hubbert proposed a theory in 1956 that predicted the behavior of oil production up until the year of about 2005. Figures 1 and 2 explain his speculation of the world oil production.

Figure 1. The Hubbert's Peak for World Oil [47]

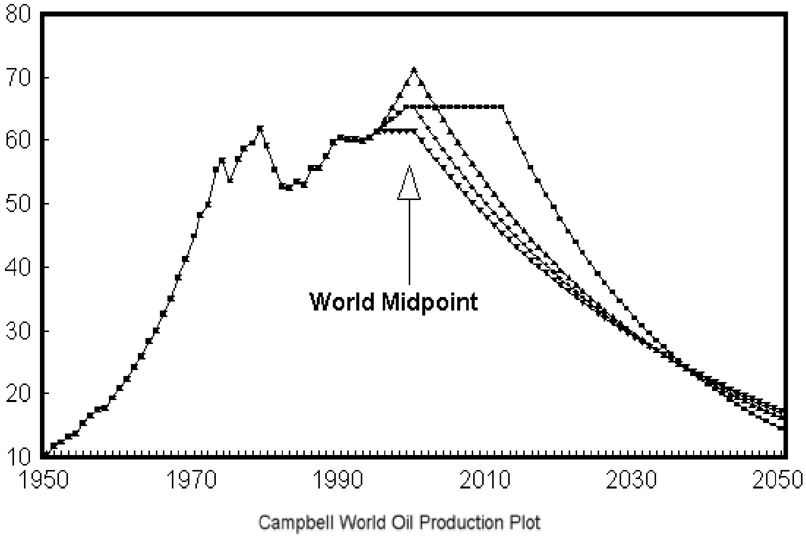
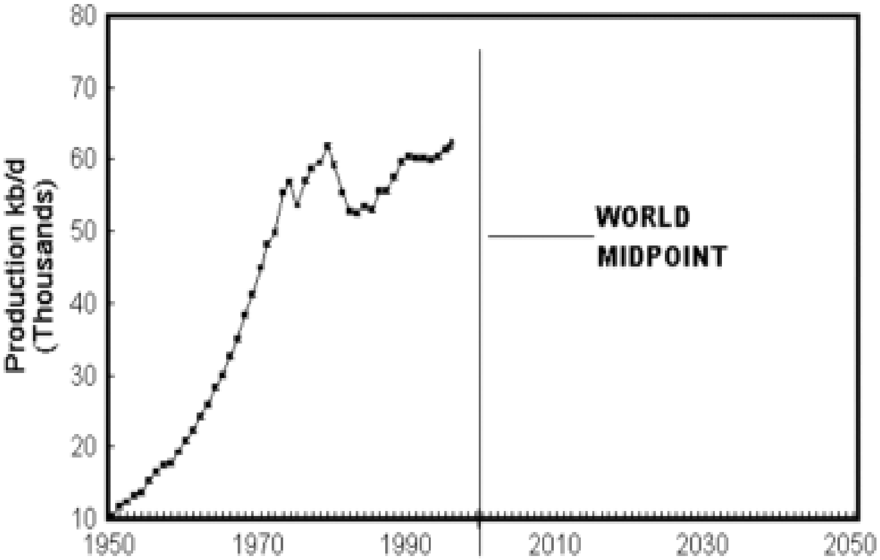


Figure 2. World Oil Production Up-Today [47]



What Hubbert was trying to interpret based on his predictions and calculations above, was that there would be a peak in U.S. Oil Production at around 1970. Despite the rejections by many involved in the oil industry, his claim eventually came to be famous when he was right about his predictions. After the peak, the oil production rate will drop and will never rise to the maximum again. Such a peak was called Hubbert's Peak. The fact that U.S. Oil production may never reach the peak again is due to the fact that our world has limited resources, especially oil.

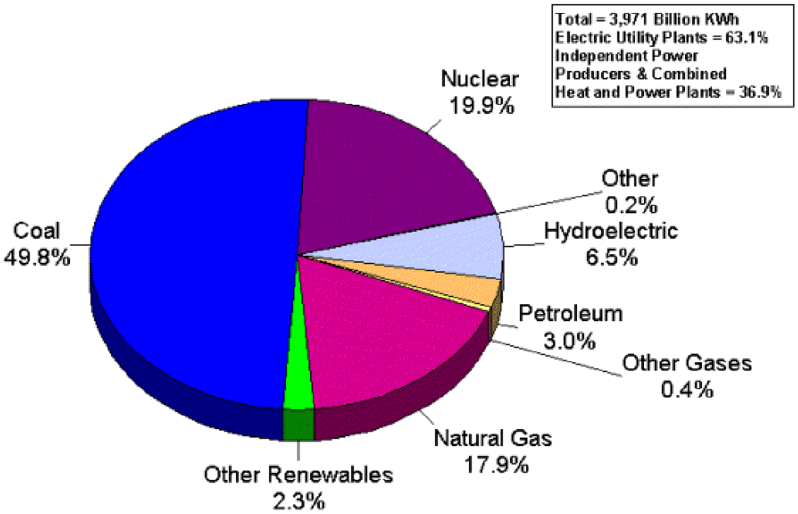
We are still looking for renewable energy resources that can hopefully replace oil. For now countries around the world still have problems dealing with Renewable Energy Technologies. What we can do for the time being is the following:

- Find out as much as possible about Renewable energy technologies and their possible benefits toward our economy and our future.
- Learn to conserve energy at home and at the workplace.
- Let leaders know how important Oil and Renewable energy technologies can be since they are the ultimate decision makers. We need to make sure that they know they are making the right choices when dealing with Renewable Energy Technologies.

3.2.2 – Cost of electricity

Calculating an average price for electricity in the U.S. over the next twenty years is a daunting task. One has to take into account the demand for electricity, the markets for all sources of electricity, costs incurred by power companies, trends, and all other events that could potentially be associated with producing and distributing electricity. The present day energy market is displayed in Figure 3, and Figure 4 displays electricity generation capacity by different fuel type over the next twenty years.

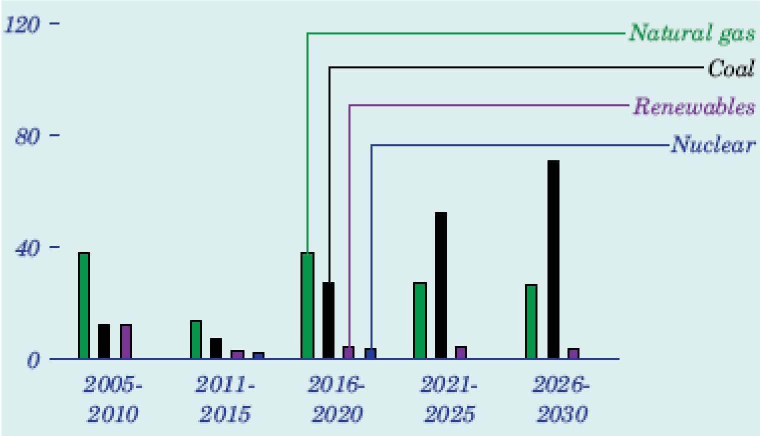
Figure 3. Electric Power Industry Net Generation (2004) [48]



Note: Conventional hydroelectric power and hydroelectric pumped storage facility production minus energy used for pumping.

According to the estimation from the Department of Energy, the average price of electricity in the U.S. will steadily go down over the next five to ten years. Consequently this is then followed by a similar increase so that the average price of electricity in the U.S. will almost be what it is today by 2026, twenty years in the future.

Figure 4. Electricity generation (Gigawatts) capacity by fuel type (2005-2030) [30]



Electricity prices are determined primarily by the costs of generation, which make up about two-thirds of the total retail price. The 2004-2005 spikes in natural gas and petroleum prices, along with elevated coal prices, led to a jump in electricity prices. According to these estimates, average retail prices (in 2004 dollars) fell to 7.1 cents per kilowatt-hour in 2015, as new sources of natural gas and coal are brought on line. After 2015, natural gas and petroleum prices rise steadily, and power producers increase their reliance on lower priced coal. As a result, retail electricity prices rise gradually to 7.5 cents per kilowatt-hour by the year 2026. [31]

This price is in constant dollars, however, the actual price, taking inflation into account, will go up so that they nearly double over the next twenty years. The figure below uses an annual inflation rate of 3%. The inflation rate, which is arguably more difficult to predict than the electricity cost projections themselves, will not likely stay at 3% every year, but 3% is about average over the last ten years.

Figure 5. Average Price for Electricity in U.S. (2006-2026) [34]

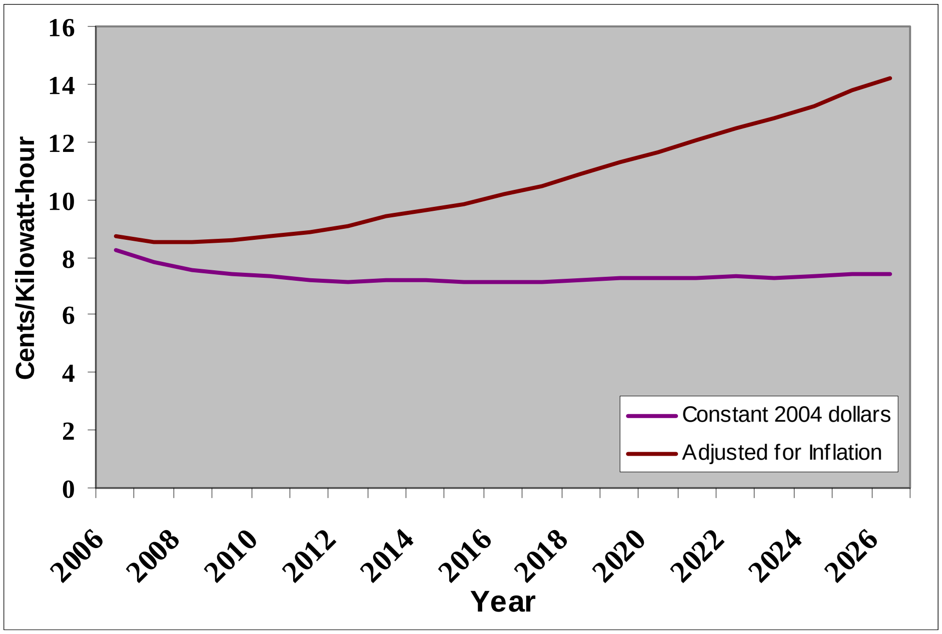
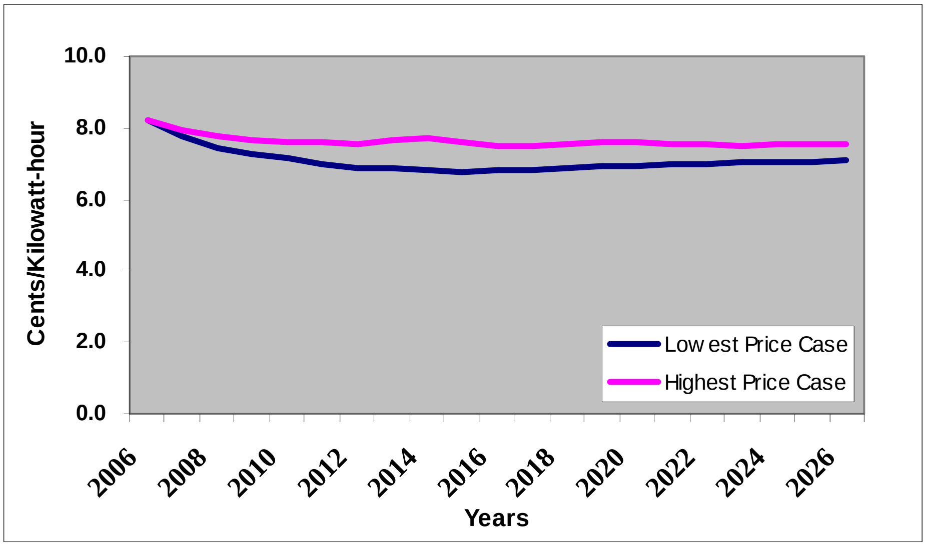


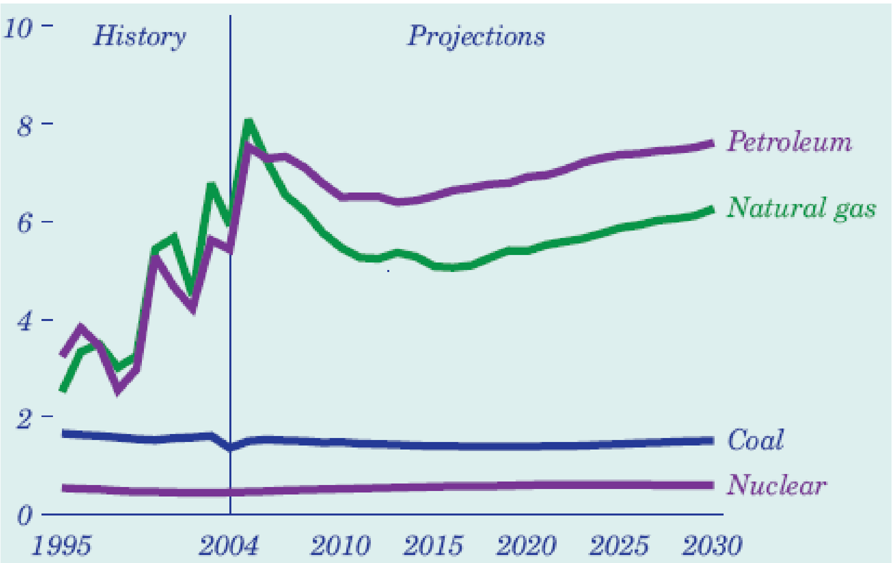
Figure 5 is one of the many projections out there, called the "reference case". Figure 6 displays two polar opposite projections that are the highest and lowest cost cases provided by the department of energy. The lowest cost case goes down for about 10 years and very slightly goes up again toward the end, and the high cost case stays relatively constant.

Figure 6. Projection of Average Electricity Price in U.S. from 2006 – 2026) [34]



Using these models on our situation, 30 households using a combined sum of 32,700 kilowatt-hours per day, we determined the final cost that these people would have to spend to pay for conventional electricity, provided they were attached to an average American grid with competitively priced power, would range from roughly $397,000, the low cost case, to roughly $428,000, the high cost case. Note that these are in constant 2004 dollars, which do not take inflation into account. The reference case, which ends up with a final cost of roughly $412,000, would cost roughly $595,000 after taking inflation into account. Figure 7 shows price projections for these choices gathered from the Department of Energy's annual energy outlook. They took into account for the price of the cost of the fuels only. The actual cost to consumers is a function of the costs for fuel, operations, maintenance, and capital. In the reference case from Figure 5, fuel costs account for about two-thirds of the generating costs for new natural-gas fired plants, less than one-third for new coal-fired units, and less than one-tenth for new nuclear power plants in 2030.

Figure 7. Fuel and generators prices 1995-2030 (2004 dollars per million Btu) [30]



3.2.3 – Environmental and Health Problems

The most common source of electricity, coal, is the lowest cost and most abundant domestic energy resource. It is also a leading cause of smog, acid rain, global warming, and air toxics. In an average year a typical coal plant generates the following [32]:

- 3,700,000 tons of carbon dioxide (CO_2), the primary human cause of global warming--as much carbon dioxide as cutting down 161 million trees.
- 10,000 tons of sulfur dioxide (SO_2), which causes acid rain that damages forests, lakes, buildings, and forms small airborne particles that can penetrate deep into lungs.
- 500 tons of small airborne particles, which can cause chronic bronchitis, aggravated asthma, and premature death, as well as haze obstructing visibility.
- 10,200 tons of nitrogen oxide (NO_2), as much as would be emitted by half a million late-model cars. NO_2 leads to formation of ozone (smog), which inflames the lungs by burning through lung tissue making people more susceptible to respiratory illness.
- 720 tons of carbon monoxide (CO), which causes headaches and places additional stress on people with heart disease.
- 220 tons of hydrocarbons, volatile organic compounds (VOC), which form ozone.
- 170 pounds of mercury, where just 1/70th of a teaspoon deposited on a 25-acre lake can make the fish unsafe to eat.
- 225 pounds of arsenic, which will cause cancer in one out of 100 people who drink the water containing 50 parts per billion.
- 114 pounds of lead, 4 pounds of cadmium, other toxic heavy metals, and trace amounts of uranium.

There are initiatives in place in the United States attempting to put a stop to coal pollution, by both emissions regulation and funding research, including the one billion dollar *FutureGen* initiative to build the world's first integrated sequestration and hydrogen production research power plant. The $1 billion dollar project is intended to create the world's first zero-emissions fossil fuel plant. [34]

Natural gas and Oil are also major contributors to these environmental problems. Although not as bad as coal, they each have their own share of pollutants. Table 1 shows how they compare to coal in producing the most problematic pollutants.

Table 1. Fossil Fuel Emission Levels - Pounds per Billion Btu of Energy Input [35]

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0	0.007	0.016

3.3 – ALTERNATIVE RESOURCES

Why is there a strong interest in renewable energy technologies? One good reason is that the conventional energy systems are the principal source of air pollution and greenhouse gases. Also they require export of millions barrels of oil per day. The renewable energy can similarly provide electricity, transportation fuels, heat and light for buildings but with much less harm to the environment. With the dramatic advances in technologies, renewable energy technologies can become major contributors to the United States and global energy supplies over the next several decades.

Solar energy uses PV technology, which consists of solar cells units, to convert sunlight into electricity. Solar PV systems are often used as distributed energy resources to reduce electricity transmission and distribution. Currently efforts have been done to improve the efficiency of converting sunlight to electricity and materials that are used to reduce the cost of manufacturing and the production of solar devices. PV technology is already widely competitive for household lighting and other domestic uses in rural areas of developing countries.

Wind energy is generated by turbines, which typically consist of two or three blades rotating about a horizontal axis and driving a gearbox and generator. Over the past two decades, the generating capacities of individual units have grown from 50 kW to an average of 900 kW. Severe structural stress over a long period is probably one of the main problems that have been focused on up until now. Approaching designs focus on improving the mechanical properties of the materials and systems of the turbine.

Energy from biomass, which include wood, landfill gas, and ethanol made from corn, accounted for about 3.4% of the United States primary energy supply. Some of potential benefits of renewable bioenergy include; its CO_2 emissions are largely balanced by the next crop's uptake. It helps remove animal and plant wastes, reduces oil imports, and it generates jobs and income in rural areas. But each year there are million tons of dry residues from crop and forestry and other wastes.

The market value of renewable systems perceives to be risky due to its high costs and unfamiliarity to users. Solar and wind systems are immune to the risk of fuel cost increases. With the competition of low-cost from fossil fuels, renewable energy technology faces difficulties in achieving market and production scales large enough to bring costs down.

3.3.1 – Availability of Renewable Energy

There had been efforts being put into harnessing renewable energy over the few decades in a more efficient way in order to reduce the cost. Renewable resources provided about 6.6 quads on primary energy to the United States in 2000 out of the total US consumption of 98.5 quads. From the total consumption, there were 38 quads from oil, 23 quads from coal, 23 quads from natural gas, and 8 quads from nuclear reaction. As for renewable energy, 3.3 quads were from biomass, 2.8 from hydroelectric generation, .32 from geothermal sources, .07 from solar energy, and .05 from wind turbines.

We know that at a yet unknown time in the relatively near future, the world will run out of one of its primary sources of energy, fossil fuels. Without these energy sources we will be forced to use renewable energy sources. The only uncertainty here is whether or not our technology will be capable of supporting our ever-growing energy needs when the time comes. As it stands now, our advancing renewable energy technologies have yet to show any serious competition to fossil fuels, not only because the price of oil, although rising, is so low, but because we have yet to find an energy source that can be utilized cheaply enough, and on a large enough scale to be worth using, despite the environmental benefits they present.

The renewable energy sources that have the potential for such growth, that we know of include solar energy, wind energy, and biomass energy. These sources have become cheaper over the years as we've found ways to draw energy from these sources more efficiently and using cheaper materials.

Solar energy is one of the more promising energy sources, as it doesn't have the unpredictability of wind and the inefficiency of biomass. There are many separate but similar technologies currently available to capture solar energy, some with efficiencies over 30%, and some cheaper but not as efficient. There has also been the development of methods for utilizing this energy source more conveniently, i.e. using thin film applied to the surfaces of buildings.

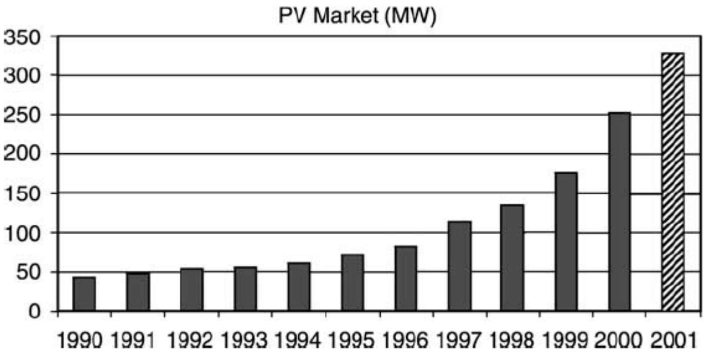
Wind energy also shows a great deal of promise. In fact, in areas with significant winds they already can be competitive with fossil fuels with the help of tax incentives. However, there is still much room for improvement of this technology. With the development of stronger, lighter, and more fatigue-resistant materials for blades, as well as higher performance and lower cost power electronics, wind power could potentially give fossil fuels a run for their money even before they run out.

Biomass fuels, while having little potential to take over as the world's primary energy source, show great potential in supplementing it, by recycling waste products we already produce. Growing fields of biomass crops isn't currently a feasible concept because using plants to collect solar energy has a terrible efficiency in the order of 1% and the cost of collecting and transporting those plants is rather high. Current implementations include wood, landfill gas, and ethanol, which can be used as an additive to regular gasoline. Scientists hope to develop a proper enzyme that will be able to use waste biomass products such as cornhusks to create energy.

3.3.2 – PV technology

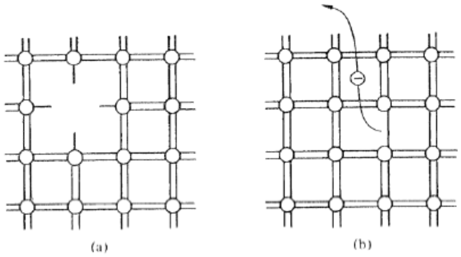
Since 1950, PV cells have been used in the spacecraft; the interest in using PV cells was induced by the increasing cost of the conventional crude oil. Ever since the oil embargo in the 1970s, there was a steady growth rate of using PV cells. Within most recent years, the PV cells industry is in an explosive period of growth. The government is subsidizing urban residents to use the PV cells. The PV market is increasing with 30% per annum over the last couple years (see Figure 8).

Figure 8. Growth in PV module industry (1990-2001) [16]



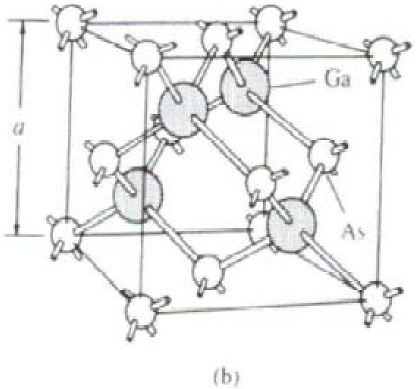
The PV effect is the process through which PV cells convert sunlight into electricity. Sunlight is composed of different wavelengths, and each wavelength has a specific amount of energy, or photons, the energy of light. When sunlight strikes the surface of a solar panel, some wavelengths are absorbed. This absorbed amount of energy is enough to free an electron from its normal position that is associated with the crystal lattice of a semiconductor, and becomes the current in an electrical circuit. Inside the PV cells, and there are two types of moving particle that produce current, “holes” and electrons (Figure 9a). When an electron is freed, it creates a “hole” in the semiconductor crystal lattice (Figure 10), and this created “hole” can be view as a particle by the missing electron. PV cells have a very unique property, which has internal electric field, which provide the voltage to drive the free electrons and holes inside the semiconductor, and we will go into detail of how the internal electric field is created.

Figure 9. 2-D Semiconductor crystal lattice



(a) Missing Hole in the semiconductor crystal lattice
(b) Free electrons by absorbing photon energy.

Figure 10. 3-D Semiconductor crystal lattice



In order to induce electric fields within the PV cells, two separate semiconductors are adhered together. First is the “p” type semiconductor, corresponding to positive because of the abundance of holes; the “n” type semiconductor, corresponding to negative because it has abundance of electrons. When both p-type and n-type materials together adhered together, the holes from the p-type material will diffuse into the n-type material, and the electrons from the n-type material will diffuse into the p-type material. This reaction will occur until it reaches an equilibrium state. When these electrons and holes flow in the two semiconductors, they will create an electric field at the junction where two types of material interconnects. Then it creates a p/n junction at the interface, and the reaction creates the electric field inside the PV cells.

In PV cells, photons are absorbed by the P-type layer, which should be doped (process of adding impurity into pure silicon) in a way that will absorb as much solar energy as possible to free as many electrons as possible. The electrons are the major current carrying particles inside the semiconductor. In order to improve the efficiency of the solar panel, the electrons need to be prevented from recombining with the holes. If the electrons recombine with the holes, there will be less current and therefore lower efficiency.

3.3.2.1 – First Generation PV Cells

The first PV cells are fabricated using the silicon wafers as the starting material, and a screen-printing technology for depositing the metal contact, which is shown in Figure 11. The main advantage of this technology is the simplicity of applying the metal contact in a similar process to the printing pattern on T-shirts, but this type of solar panel cells has very low efficiency (see Figure 12). Almost 40% of its cost is attributed to the initial silicon wafer used in the cells fabrication.

Figure 11. Standard Screen Printed Solar Cells [16]

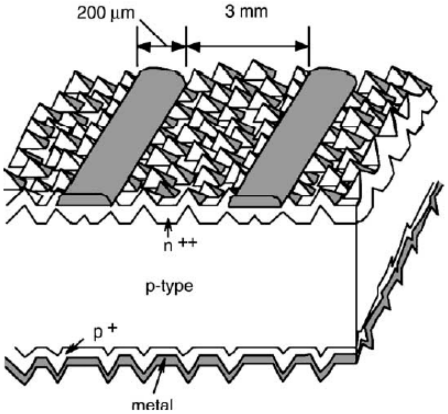
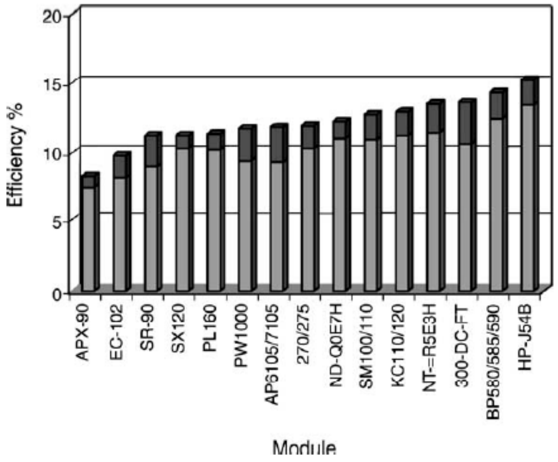
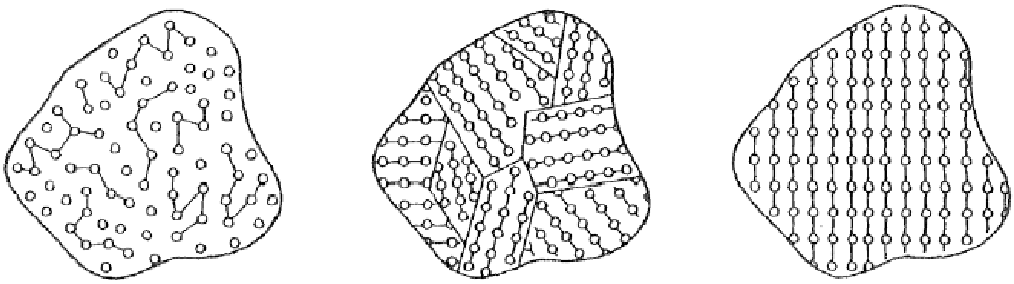


Figure 12. First Generation Module Efficiency [16]



Another type of PV cells, called HIT cells, is a combination of thin-film amorphous silicon technology and wafer-based technology. Each module typically has a 35% efficiency range. Lower efficiency PV cells use lower cost multi-crystalline silicon and the high end use the HIT cells structure on single-crystalline wafers. Figure 13 shows couple example of different types of silicon crystal structure.

Figure 13. Different Types of Silicon Crystal Structure



(a) Amorphous
No recognizable
long-range order

(b) Polycrystalline
Completely ordered
in segments

(c) Crystalline
Entire solid is made up of
atoms in an orderly array

3.3.2.2 – Second Generation PV Cells

The second-generation PV is based on thin film technology. In thin film technology, a thin layer of PV material is embedded onto a supporting silicon substrate; this reduces the number of semiconductors required to produce the product. According to the researchers, it requires approximately 100 times less material than first generation PV cells. It is possible to mass-produce, since the module (100 times larger than the individual cells) becomes the standard unit of production, instead of the individual cells. Since the requirement thickness of the semiconductor material is at a micrometer scale, almost any type semiconductor can be used cost effectively. Currently, there are many thin film technologies focused on commercial development. For example, one type of thin film cells based on the hydrogenated alloy of amorphous silicon has been developed in Japan, and used in many consumer electronic products such as pocket calculators and digital watches. In fact, many countries around the world are promoting the use of solar energy to power residential houses. Germany launched the “1000 roofs” program in the 1990s, which subsidized the installation of 1000 PV systems on the roofs of private residences (Figure 14). The Japanese government encouraged residents to install solar panels on their rooftops with a 50% government subsidy. From 1994 to 1996, approximately 1900 private residential solar panel systems each with a 3 KW rating was installed (Figure 15).

Figure 14. Grid Connected PV System in Germany [16]

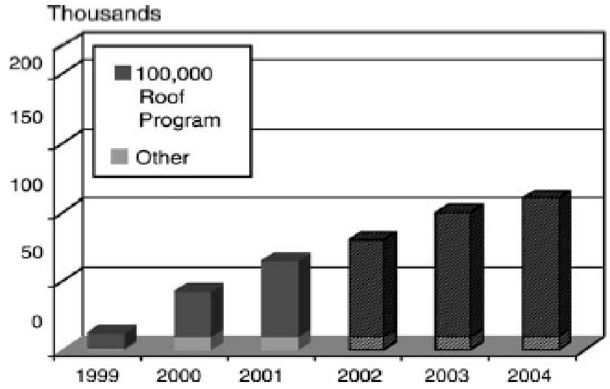
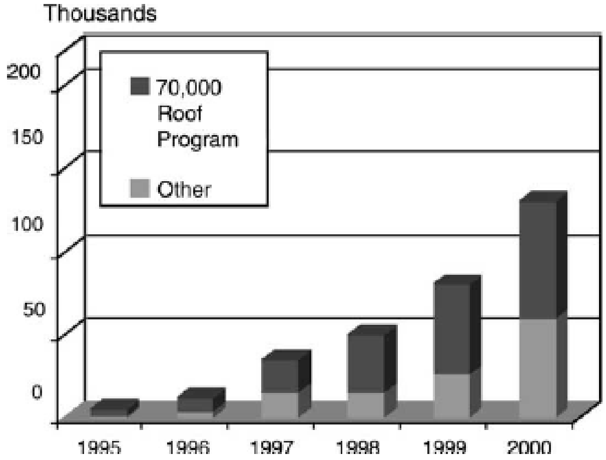


Figure 15. Grid connected PV System in Japan [16]



3.3.3 – PV technology's cost

There has been an increasing interest in using renewable energy technologies as a means of supplying energy needs in a sustainable manner. This paper describes the recent evolution of the market for solar PV and it possible future developments. It also explained the role of PV technology in competitive markets with other forms of energy resources and assessed its potential to become competitive in the future.

Figure 16. The elasticity of demand for PVs [14]

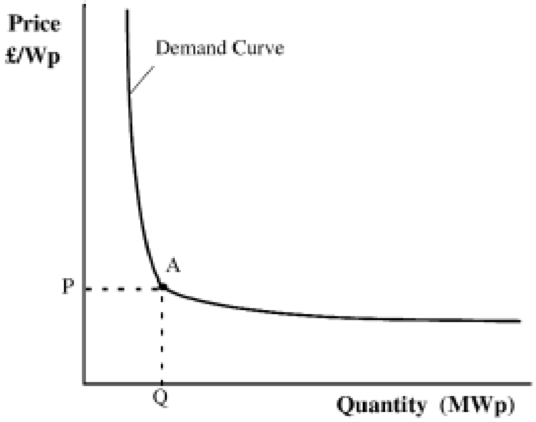


Figure 16 shows the elasticity of demand for PV technology. When the prices fall below P at an annual output greater than Q, the effect of lower costs on increasing market size will accelerate. This means that as the price of PV technology lowers, the larger markets for PV will more viable and its demand will become much higher. As long as PV technology is significantly more expensive than other technologies, the demand will be low.

In 1992, Taschini and Ianucci commented that as prices dropped from hundreds of dollars per watt in early 1970s to $10 per watt in the early 1980s and to less than $5 per watt in the early 1990s, the use of PV technology has increased. They claimed that as module prices declined from approximately $4.50 per watt in 1992 to the $2-2.50 per watt range, PV could become cost effective for fuel displacement in the diesel power market [14]

Figure 17. The size of the annual market for PVs from 1982 – 1997 [14]

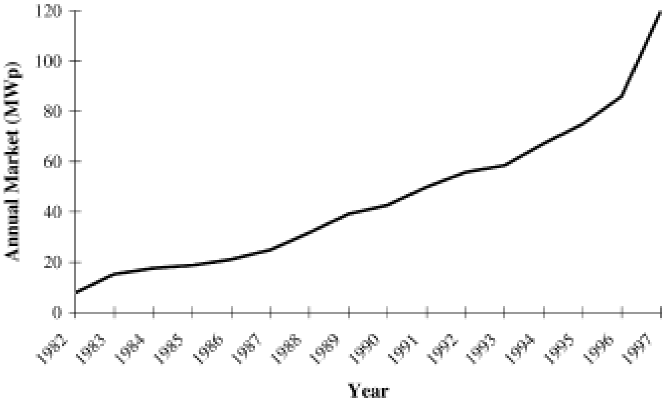


Figure 17 illustrates the annual PV global market from 1982 to 1997. Based on the graph, there was an increased from 7.8 MWp in 1982 to 120 MWp in 1997. The figure shows an increasing trend in the global market for PV technology, and it's expected to grow in the future.

Figure 18. The reduction in costs of PVs [14]

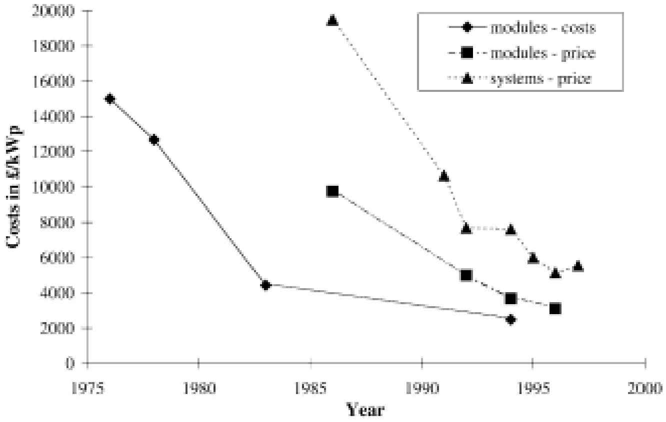
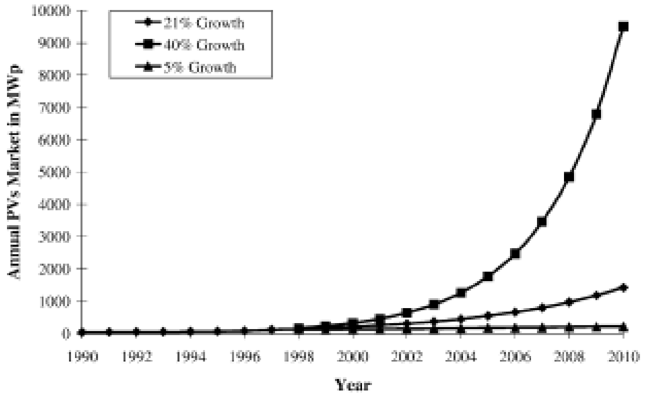


Figure 18 displays the decrease in the cost of PV systems and modules over 25 years. Based on the collected data, the PV market has grown while the costs of modules and systems have fallen. For example, Shell in 1994 observed that module costs have fallen from more than $20/Wp to around $5/Wp over the past 20 years while the production doubled every 5 years. Learning curve theory, also known as experience curve theory, has been used to analyze the decrease in PV prices with increasing deployment.

Figure 19. Future annual market size of PVs under different growth rates from 1990 – 2010 [14]



The future annual market for PVs under different growth rates is shown in Figure 19. If demand for PV continues to grow at 40%, it will reach an annual market of 9525 MW_p by 2010. To be more realistic, if demand grows at 21%, which was the average for last 15 years, it will reach an annual market of around 1430 MW_p by 2010. For the low growth rate of 5%, the annual market will only be around 226 MW_p by 2010. The actual growth of the industry is unlikely to be constant and steady. The growth can also be accelerated due to factors such as escalation of gas and oil prices, concern for energy and environment or increased emphasis on renewable energy by international funding agencies for the developing world. The low growth rates could possibly be driven by low prices in oil and gas. If the annual growth rates of 40%, 21%, and 5% are considered, and the 80% learning curve is assumed to continue, the expected cost reductions in the PV industry can be estimated.

3.3.3.1 – Break-even prices of PV system and modules

There is no widespread agreement on what should be the break-even price for PV technology in order for it to be competitive with fossil fuels for the generation of electricity. $\$1/W_p$ is considered the target for full commercial viability of grid-connected PV modules in much of the literature. The break-even price of both PV systems and modules is highly sensitive to the assumptions made on the modules and balance-of-system (BOS) prices with respect to the total PV system market price, real discount rate, capacity factor, operation and maintenance (O&M) costs, and the expected lifetime of PV systems. The break-even price is also a function of the targeted electricity cost, which is why there are large differences in the estimates of break-even prices up until now. The estimated break-even prices in 2003 for PV systems ranged from $\$1/W_p$ and $\$3/W_p$; the estimated break-even prices for PV modules ranged between $\$0.5/W_p$ and $\$1.2/W_p$. As a result, there will be different break-even prices for PV systems in generating electricity for different applications such as intermediate loads, peak loads, and building-integrated PV (BIPV) systems. The estimated break-even prices in comparison to intermediate load generation in utility-owned systems and BIPV applications were $\$0.05/W_p$ and $\$0.15/W_p$, respectively. This is based on the assumptions of a 25 years lifetime for PV systems, the capacity factor ranging from 0.15 to 0.23, and the real discount rate ranging from 5 to

11% for utility-owned applications, and 4 to 8% for building-integrated applications. It also assumed that the break-even price of modules was 60% of the total PV system market price. The formula used for calculating the levelized electricity cost (LEC) of the PV systems under these assumptions is shown in Equation 1.

Equation 1. Levelized electricity cost [15]

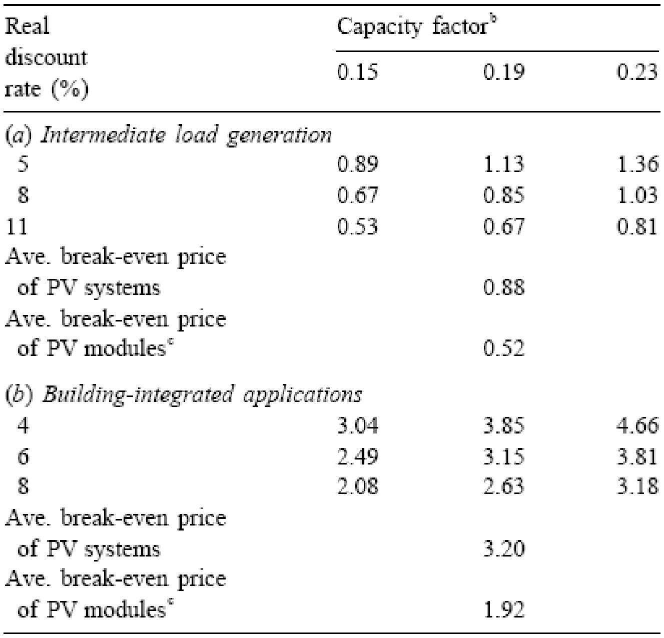
$$\mathrm{LEC} = (\mathrm{CC} \times \mathrm{CRF}) / (\mathrm{CF} \times 8760) + \mathrm{O\&M}$$

LEC is the cost of the electricity generated ($ / kWh); CC is the initial capital cost of the PV system ($ / kW_p); CRF is the capital recovery factor; CF is the capacity factor; 8760 is the number of hours/year; and O&M is the operation and maintenance cost ($ / kWh), which is assumed to be $0.002 / kWh. This formula is used to calculate the break-even prices for PV systems (module plus BOS) by solar energy technology with the LEC equal to the target price, and by considering the CC as the break-even price. The CRF can be determined using Equation 2, where r is the real discount rate and *n* is the PV system lifetime.

Equation 2. Capital Recovery Factor (CRF) [15]

$$\mathrm{CRF} = r + r/[(1+r)^n - 1$$

Table 2. Break-even prices of PV systems ($/$W_p$) sensitivity analysis [15]



Real discount rate (%)	Capacity factor[b]		
	0.15	0.19	0.23
(a) Intermediate load generation			
5	0.89	1.13	1.36
8	0.67	0.85	1.03
11	0.53	0.67	0.81
Ave. break-even price of PV systems		0.88	
Ave. break-even price of PV modules[c]		0.52	
(b) Building-integrated applications			
4	3.04	3.85	4.66
6	2.49	3.15	3.81
8	2.08	2.63	3.18
Ave. break-even price of PV systems		3.20	
Ave. break-even price of PV modules[c]		1.92	

Table 2 describes the break-even prices for real discount rates ranging from 5 to 11% for intermediate load generation and from 4 to 8% for building-integrated applications with capacity factors of 0.15, 0.19, and 0.23.

For example, using Equation 1, we can find the break-even price for intermediate load generation with a target levelized electricity cost (LEC) of \$0.05 / kWh, real discount rate of 5% (*r*), 25 years lifetime (*n*), capacity factor of 0.15 (CF), and O&M cost of \$0.002. First, we have to find the CRF using Equation 2. The calculations are shown below.

- CRF = 0.05 + (0.05 / [(1+0.05)^{25} – 1]
- CRF = 0.07095

Then solving for break-even price using Equation 1.

- \$0.05/kWh = (CC * 0.07095) / (0.15 * 8760) + \$0.002/kWh
- Solve for CC which come out to be \$888/kW$_p$ or \$0.89/W$_p$
- The break-even price of this PV system is \$0.89/W$_p$ for the intermediate loading generation.
- The average break-even price for PV modules, which is 60% of the total PV system market price, is about \$0.53/W$_p$.

From Table 2, it's important to note that the break-even price of PV modules (\$0.52 for intermediate load generation and \$1.92 for building-integrated applications) is one of the factors that determine the overall installed PV system market price, so the assumption that the module cost in the future will be about 60% of the PV system market price might not be accurate.

3.3.3.2 – Cost Reduction of PV Technology

There needs to be a significant reduction of the cost of PV technology in order for it to displace the use of fossil fuels in electricity generation. Technological advancement and other factors have continuously reduced the costs of PV technology since it was first introduced in the 1970s, and this trend of decreasing cost is expected to continue in the future. One main question arises: when will the decline unit costs for PV technology will result in a significant market value?

Experience curve analysis is one method that can be used to answer this question. It has been used in the past to assess the prediction of PV technology's spread through the market. Some of these analyses calculated the progress ratio (the relationship between prices and cumulative shipments) of PV modules since it first became commercialized in the 1970s. The experience curve is used to describe how unit costs decrease with increasing production growth. It's characterized by the constant percentage of decline in costs with each doubling of cumulative production. This is usually defined by the expression described in Equation 3.

Equation 3. PV Experience curve [15]

$$\text{Price at year } t = P_0 * X^{-E}$$

P_0 is a constant equal to the price of one unit at cumulative production (at time zero, t_0), X is the cumulative unit production at year *t*, and E is the experience index. The experience index reflects the relative cost reduction ($1-2^{-E}$) with each doubling of cumulative production. The value 2^{-E} denotes the progress ratio (PR) and measures the relationship between the increase in cumulative production and the decrease of unit costs. The PR is used to indicate the progress in cost reduction for a given technology by quantifying the percentage cost declines for each doubling of cumulative production. For example, a PR of 85% indicates that costs are reduced by 15% at every doubling of cumulative production. The experience curve describes reduction in total costs, which include capital, marketing, labor, etc. as production increases.

This study provides the most updated calculation of the progress ratio of PV modules using current data of shipments and average selling prices. The worldwide cumulative shipments of PV have increased since the 1970s from $4MW_p$ in 1976 to $2380MW_p$ at the end of 2002 (see Figure 20). With many factors involved, it's hard to predict what the prospects of PV technology will be. Experience curves can be used to predict the prospects of PV market viability by calculating the PV cumulative production that is required to reach a given break-even price, assuming different PR values and market growth. The PV system break-even price is the price that PV systems have to reach in order to be competitive with other sources for electricity generation without subsidies or tax credits.

In a previous study by Maycock and Wakefield published in 1975, the authors analyzed the pre-commercialization trend in the prices of PV modules, and documented that, between 1965 and 1973, PV modules had an experience curve with a PR of 80%. In 1993, Williams and Terzian found that the experience curve of PV modules between 1976 and 1992 had a PR of 82%. In 2000, Harmon calculated that the PR of PV modules between 1968 and 1998 at 80% [15].

Figure 20. Average selling price of PV modules from 1976 – 2002 [15]

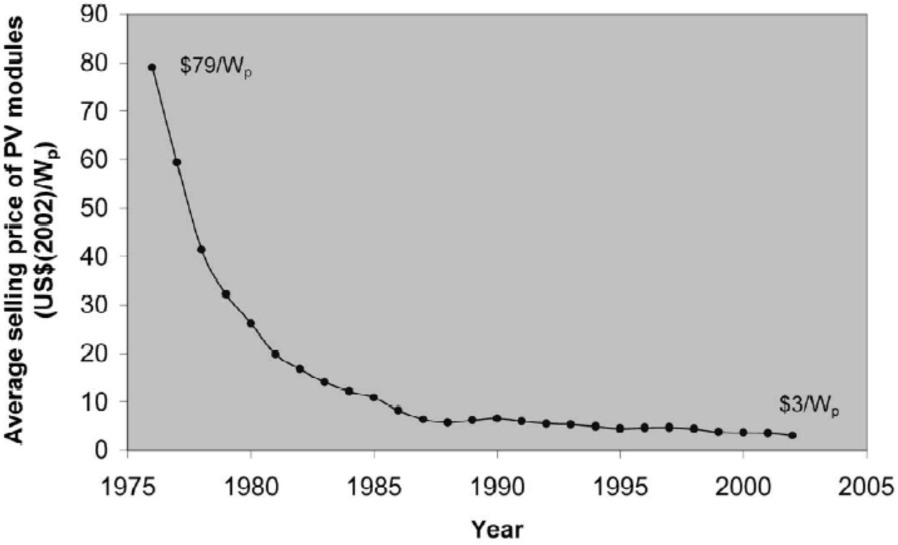


Figure 21. Cumulative Worldwide shipments of PV modules from 1976 – 2003 [15]

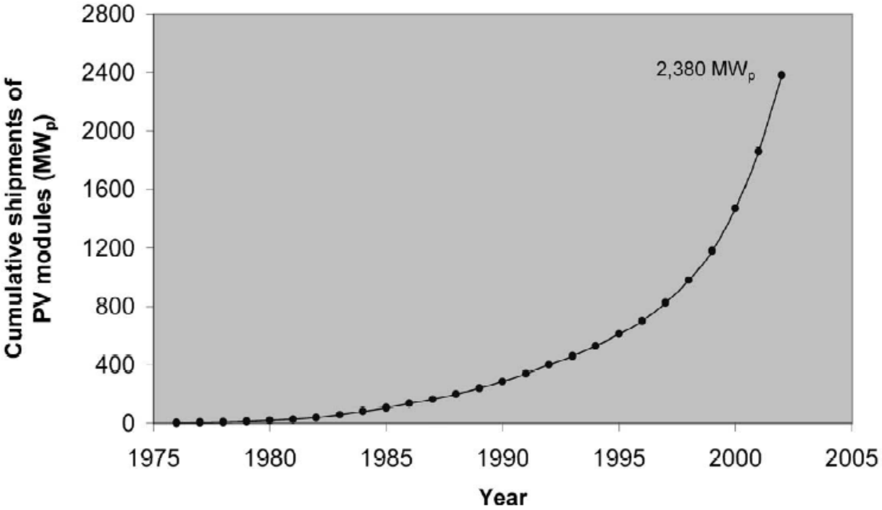
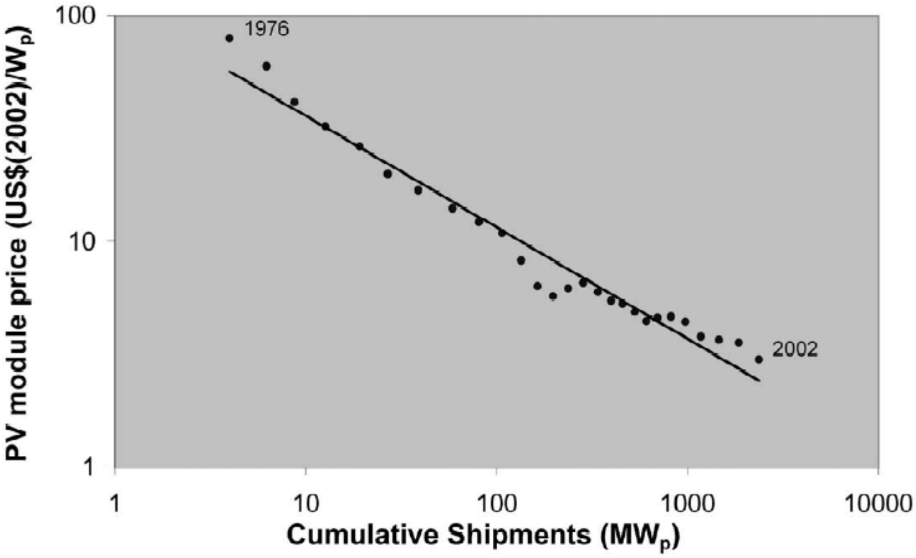


Figure 22. PV module experience curve from 1976 – 2002 [15]



According to the current data collected by Maycock, the average selling price of PV modules was \$79/W_p in 1976 and \$3/W_p in 2002 with an appropriated cumulative shipment of 2389MW_p (see Figure 21). If these data values are used in the experience curve equation (Equation 3), a PR of 75% will be obtained which mean 25% of price reduction of PV modules price for each doubling cumulative shipment. Figure 23 shows a log-log plot in which the average selling price of PV modules is a function of cumulative shipments between 1976 and 2002. The derivation for the PR ratio is shown below:

- Price at year t (2002) = \$3/W_p
- P_0 = \$79/W_p
- X = 2380 MW_p

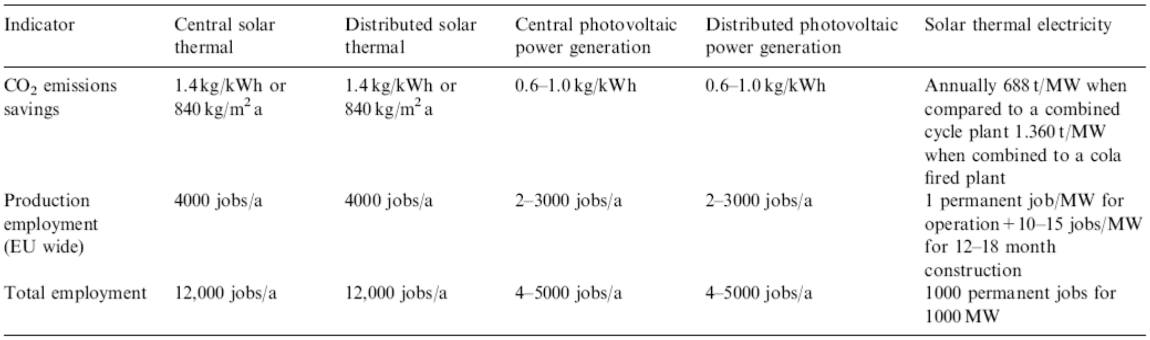
When you substitute everything in and solve for *E,* which is about 0.42069. The reduction in cost is equal to $1\text{-}2^{-E}$ which equals 25%. This expected PR value is lower than the other studies mentioned, possibly due to the different estimation of PV module prices (P_0) in the mid-1970s.

There are factors such as market growth that could affect the progress ratio. The experience curve shows the investment necessary to make PV competitive, but it does not show when the technologies will break-even. The time of break-even depends on the deployment rates, which can be influenced by decision-makers through policy. Based on historical annual growth rates of 15%, PV modules will reach the break-even point around the year 2025; doubling the rate of growth will move the break-even point 10 years ahead to 2015. In order to bring the prices to the break-even point, investments or learning efforts are necessary. The difference between the actual price and break-even price and the additional cost, also known as learning investments, is the indication for the required resources for learning. Learning investments are investments in learning to make the technology cost-efficient.

3.3.4 – Environmental Impacts

Solar energy technologies provide obvious environmental advantages in comparison to conventional energy sources and contribute to the sustainable development of human activities (see Table 3).

Table 3. Environmental and social indicators of solar energy technologies [17]



Indicator	Central solar thermal	Distributed solar thermal	Central photovoltaic power generation	Distributed photovoltaic power generation	Solar thermal electricity
CO_2 emissions savings	1.4 kg/kWh or 840 kg/m^2 a	1.4 kg/kWh or 840 kg/m^2 a	0.6–1.0 kg/kWh	0.6–1.0 kg/kWh	Annually 688 t/MW when compared to a combined cycle plant 1.360 t/MW when combined to a cola fired plant
Production employment (EU wide)	4000 jobs/a	4000 jobs/a	2–3000 jobs/a	2–3000 jobs/a	1 permanent job/MW for operation + 10–15 jobs/MW for 12–18 month construction
Total employment	12,000 jobs/a	12,000 jobs/a	4–5000 jobs/a	4–5000 jobs/a	1000 permanent jobs for 1000 MW

Not counting the depletion of the exhausted natural resources, solar energy technologies advantage is related to the reduced CO_2 emissions, and absence of any air emissions or waste products during their operation. Concerning the environment, the use of solar energy technologies has additional positive implications such as [17]:

- Reduction of the emissions of the greenhouse gases (mainly CO_2, NO_x) and prevention of toxic gas emissions (SO_2 particulates);
- Reclamation of degraded land;
- Reduction of the required transmission lines of the electricity grids; and
- Improvement of the quality of water resources

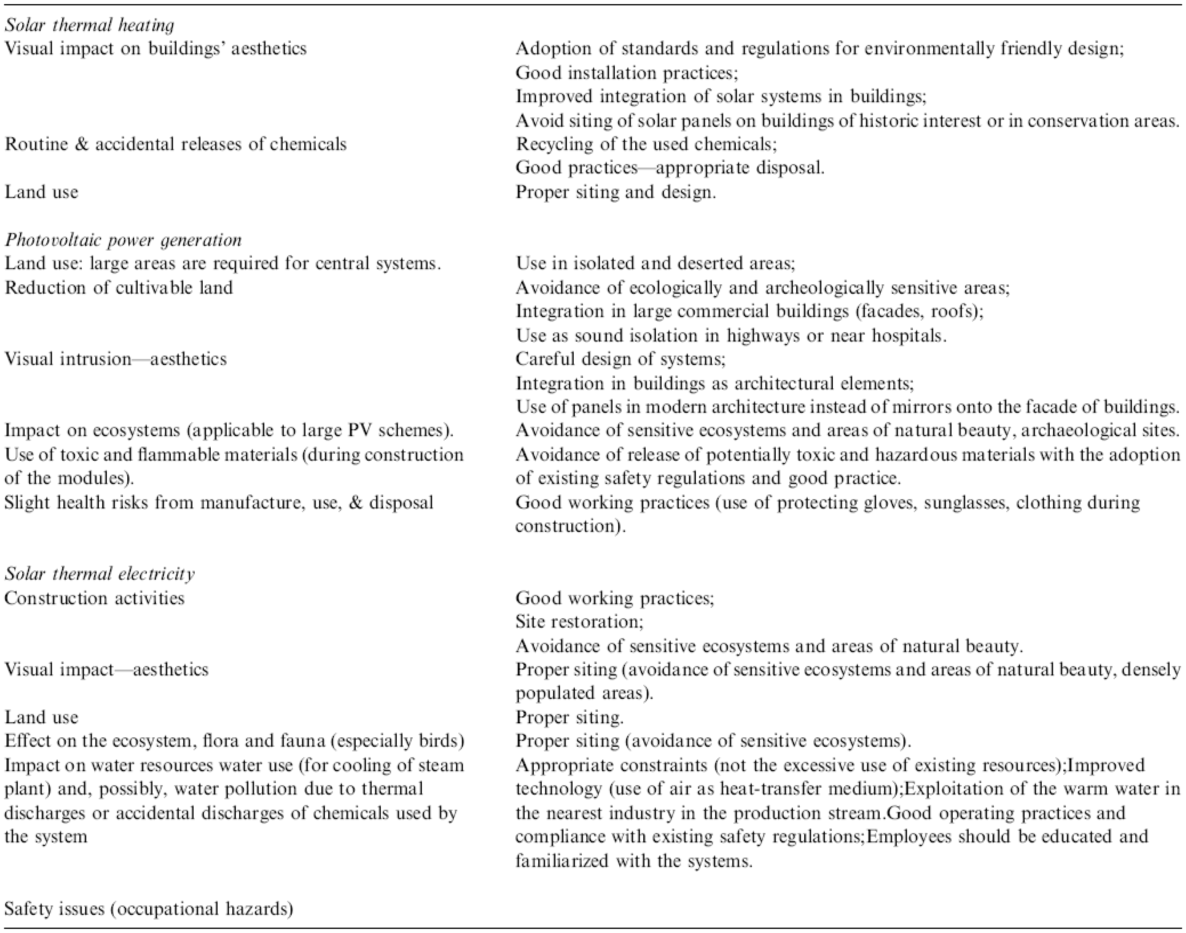
In regard the socio-economic viewpoint, the benefits of the exploitation of solar energy technologies comprise:

- Increase of the regional/national energy independency;
- Provision of significant work opportunities;
- Diversification and security of energy supply;
- Support of the deregulation of energy markets; and
- Acceleration of the rural electrification in developing countries.

Furthermore, unfavorable effects of solar energy technologies are usually minor and they can be minimized by appropriate mitigation measures. The potential environmental burdens of solar energy technologies are regularly site specific, depending on the size and nature of the project. As it is obvious from Tables 5 and 6, these burdens are usually associated with the loss of amenity and the impacts can be minimized by:

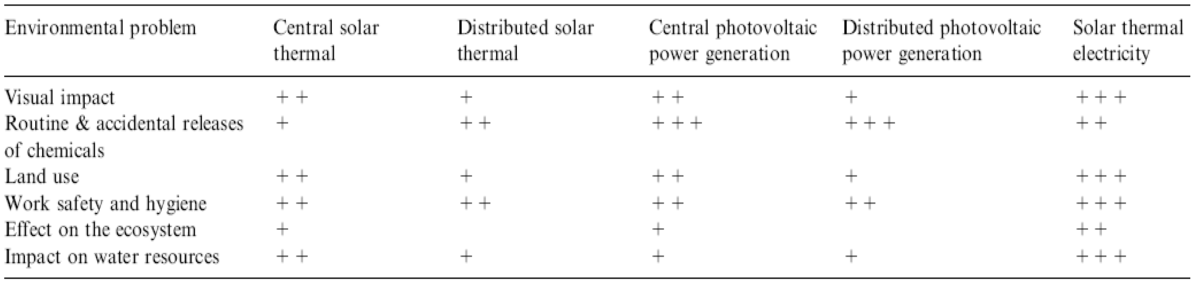
- The appropriate siting of central solar systems, which involves careful evaluation of alternative locations and estimation of expected impact (away from densely populated areas and not in protected areas or areas of significant natural beauty); the residential solar systems can be installed anywhere, especially integrated in the roofs.
- The appropriate operational practices (including rational water use, safety measures, waste disposal practices, use of biodegradable chemicals, etc.).
- The engagement of the public and relevant organizations in the early stages of planning, in order to ensure public acceptance;
- The use of the best available technologies/techniques and the improvement of technology. For example, using air as the heat-transfer medium in central tower systems;
- The integration in the building's shell;
- The sensible planning constraints and pre-development assessments (such as on water use, habitat loss, and estimation of expected CO_2 savings);
- The training of workers, use of special sunglasses during operation and construction, use of heat insulating uniforms, familiarization with the system;
- The re-establishment of local flora and fauna, giving the environment enough time to come up to its previously state again; and
- Thorough Environmental Impact Assessment Studies for central solar systems.

Table 4. Solar energy technologies' negative impacts [17]



Solar thermal heating	
Visual impact on buildings' aesthetics	Adoption of standards and regulations for environmentally friendly design; Good installation practices; Improved integration of solar systems in buildings; Avoid siting of solar panels on buildings of historic interest or in conservation areas.
Routine & accidental releases of chemicals	Recycling of the used chemicals; Good practices—appropriate disposal.
Land use	Proper siting and design.
Photovoltaic power generation	
Land use: large areas are required for central systems. Reduction of cultivable land	Use in isolated and deserted areas; Avoidance of ecologically and archeologically sensitive areas; Integration in large commercial buildings (facades, roofs); Use as sound isolation in highways or near hospitals.
Visual intrusion—aesthetics	Careful design of systems; Integration in buildings as architectural elements; Use of panels in modern architecture instead of mirrors onto the facade of buildings.
Impact on ecosystems (applicable to large PV schemes).	Avoidance of sensitive ecosystems and areas of natural beauty, archaeological sites.
Use of toxic and flammable materials (during construction of the modules).	Avoidance of release of potentially toxic and hazardous materials with the adoption of existing safety regulations and good practice.
Slight health risks from manufacture, use, & disposal	Good working practices (use of protecting gloves, sunglasses, clothing during construction).
Solar thermal electricity	
Construction activities	Good working practices; Site restoration; Avoidance of sensitive ecosystems and areas of natural beauty.
Visual impact—aesthetics	Proper siting (avoidance of sensitive ecosystems and areas of natural beauty, densely populated areas).
Land use	Proper siting.
Effect on the ecosystem, flora and fauna (especially birds)	Proper siting (avoidance of sensitive ecosystems).
Impact on water resources water use (for cooling of steam plant) and, possibly, water pollution due to thermal discharges or accidental discharges of chemicals used by the system	Appropriate constraints (not the excessive use of existing resources);Improved technology (use of air as heat-transfer medium);Exploitation of the warm water in the nearest industry in the production stream.Good operating practices and compliance with existing safety regulations;Employees should be educated and familiarized with the systems.
Safety issues (occupational hazards)	

Table 5. Grade of the potential negative environmental impacts of solar technologies [17]



Environmental problem	Central solar thermal	Distributed solar thermal	Central photovoltaic power generation	Distributed photovoltaic power generation	Solar thermal electricity
Visual impact	+ +	+	+ +	+	+ + +
Routine & accidental releases of chemicals	+	+ +	+ + +	+ + +	+ +
Land use	+ +	+	+ +	+	+ + +
Work safety and hygiene	+ +	+ +	+ +	+ +	+ + +
Effect on the ecosystem	+		+		+ +
Impact on water resources	+ +	+	+	+	+ + +

3.3.4.1 – Environmental impacts from solar thermal heating systems

The productions of solar thermal systems require reasonable quantities of materials and insignificant amounts are also consumed during the operation. At that time, the only potential environmental pollutant arises is from the coolant change, which can be easily controlled by good working practice. The accidental leakage of coolant systems can cause fire and gas releases from vaporized coolant, unfavorably affecting public health and safety. On the contrary, the large-scale deployment of solar thermal technologies will significantly reduce the combustion of conventional fuels and the environmental impacts associated with these fuels.

3.3.4.2 – Environmental impacts from PV power generation

PV technologies seem to have benign environmental impacts; generating no noise or chemical pollutants during use. It is one of the most viable renewable energy technologies for use in an urban environment, replacing existing building cladding materials. It is also an attractive option for use in scenic areas and National Parks, where the avoidance of pylons and wires is a major advantage.

3.3.4.3 – Environmental impacts from solar thermal electricity

Up until now, there is a limited deployment of solar thermal electricity. This means that there is little actual experience of the environmental impacts that such a scheme may have. Similarly to other solar energy technologies, solar technology electricity systems present the basic environmental benefit of the displacement or the avoidance of emissions associated with conventional electricity generation. During their operation, these systems have no emissions. Some emissions do arise from other phases of their life cycle (primarily materials processing and manufacture), but they are lower, compared to those avoided by the systems operation.

3.3.4.4 – Conclusions and Recommendations

Solar energy technologies present tremendous environmental benefits when compared to the conventional energy sources. In addition to not exhausting natural resources, their main advantage is almost total absence of almost any air emissions or waste products. In other words, solar energy can be considered as an almost absolute clean and safe energy source [17]. Furthermore, the use of solar energy technologies can have additional environmental benefits. Solar energy technologies have the potential be employed in stand-alone applications that avoid of grid connection. It has multi-purpose applications such as combination of solar systems for water and space heating. Finally, the use of solar energy technologies has significant socio-economic benefits, such as diversification and security of energy supply, provision of significant job opportunities, support of the restructure of energy markets, reduction of the dependency on fuel imports and acceleration of the electrification of rural communities in isolated areas. On the other hand, it must be realized that no man made project can completely avoid some impact to the environment, so neither can solar energy technology installations. Potential environmental burdens depend on the size and nature of the project and are often site specific. Most of these burdens are associated with loss of amenity such as visual impact or noise. However, adverse effects are generally small and can be minimized by appropriate mitigation measures, including the use of the best available abatement technologies. Technologies or techniques that can be used to eliminate or minimize potential environmental impacts from solar energy technologies may involve:

- The use of air emission or odor control equipment;
- Design tools for optimal design and siting of the installations;
- Best practice guidelines,
- Improved pieces of equipment (such as gearless or lubricant-free motors); and
- A completely innovative design (e.g., closed- cycle plants, submerged plants, etc.).

It is up to the involved factors such as investors, developers, and permitting authorities, to make the appropriate decisions by taking environmental issues into serious consideration. Furthermore, an Environmental Impact Assessment for central solar systems, which should estimate the magnitude of potential environmental impacts and propose appropriate mitigation measures, can play a significant role to proper project design and to a subsequent project public acceptance.

4. OBJECTIVES OF THE STUDY

Currently, conventional resources such as oil and coal are able to provide us with enough energy with little cost. The increased usage of these limited resources will decrease their availability in the near future. Renewable resources such as solar, wind, and biomass are alternative energies, which are environmentally friendly and abundant in nature, are able to take away the burdens of our conventional energy and may replace it in the near future.

Why choose solar energy over other renewable resources? Solar energy is free and could be installed almost anywhere if there is sunlight. Developing a wind farm would require that region to be windy which considered being a constraint. In using biomass, energy is lost in chemical processes and wastes are produced.

Today, grid electricity from a conventional energy plant would be an ideal form of energy for use throughout the United States. The transmission and distribution system is quite extensive and dense in the central part of the country. Access to electricity is fairly widespread within the distribution system, but a bulk of the peri-urban and rural community where people do not have electricity. PVs can be a substitute for grid electricity in areas where electricity is not available. One alternative is to build a solar farm near an urban or rural area that would be able to provide enough electricity for a community or install each individual house with a PV system. The electricity produced can be used for specific needs such as providing light, cooking, and for electric-powered appliances.

In this study, two proposed PV system models – a case that involves individual PV system on every household and another case with a solar farm – are implemented in a rural community with approximately 30 households, which is unable to connect to the grid. For both cases, there are important objectives that have to be fulfilled, which include low cost, efficiency, safety, longevity, and sufficient power.

- Low cost – the cost of making the design has to be affordable for the community or each individual household. They might not have enough financial support to pay for PV systems. The total cost will be important for people and we will focus on the design that is low in cost.

- Efficiency – The efficiency of the solar panels is also important because we want to minimize the amount of land require to build the design.

- Longevity – The long life of the design is also important. We want the design to last as long as possible to maximize the time usage before making some replacements or repairs.

- Sufficient power – The design has to be able to generate enough electricity for 30 households or for an individual household. The design also needs to be able to provide enough electricity during the day and even at night when no sunlight is available.

- Safety – The design of the PV systems has to be safe when operated by the community.

5. METHODS AND PROCEDURES

5.1 – OBJECTIVES

The objectives for the design were compared to each other using the pair wise comparison chart [20]. The objectives are listed on both rows and columns in the matrix and then compared on a pair by pair basis, proceeding in a row-by-row fashion. Numerical values are assigned to each objective based upon their importance compared to each other. The numbers are summed up and the objectives with the highest score would be the most important factor of the design.

Table 6. Pairwise comparison chart for Objectives

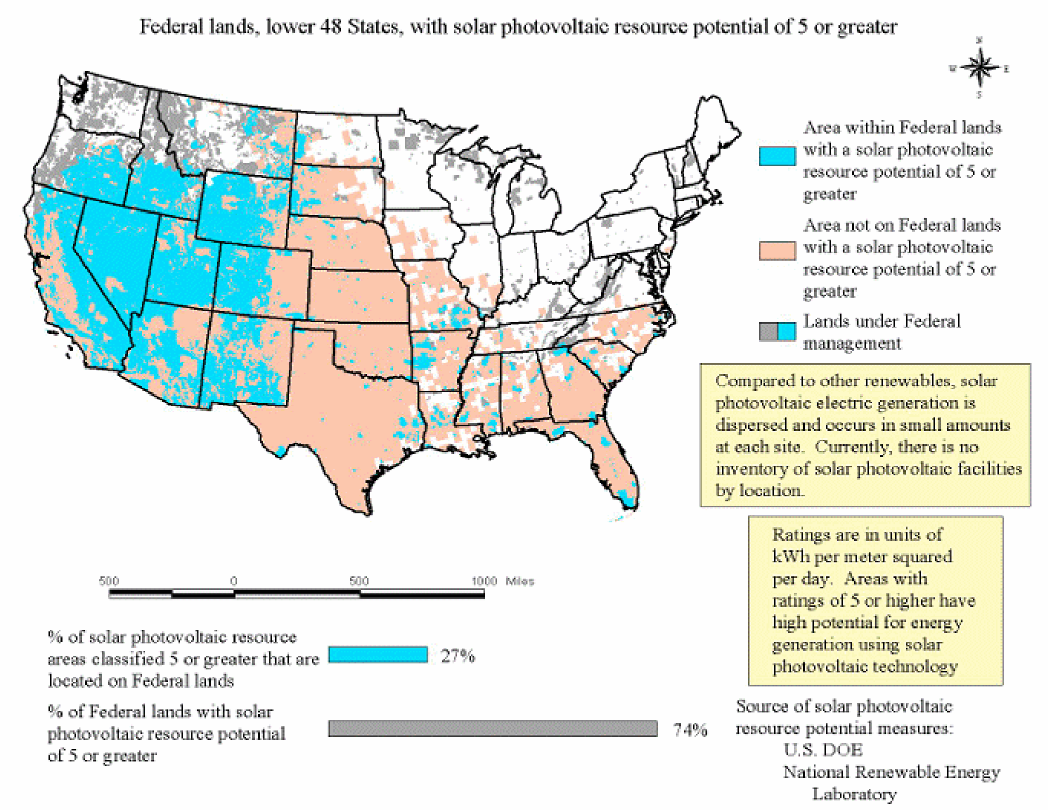
Objectives	Low Cost	Efficiency	Longevity	Sufficient Power	Safety	Score
Low Cost	-------	1	1	1	1	4
Efficiency	0	-------	1	0	1	2
Longevity	0	0	-------	0	0	0
Sufficient Power	0	1	1	-------	1	3
Safety	0	0	1	0	-------	1

From Table 6, low in cost is the most important factor, while sufficient power is the second most important. Choosing the different type of solar panel models will not change the safety of the design. Efficiency in this case was not that important for the solar farm because the PV system is built in a rural area where land is available for installment. In the individual case, the efficiency of the solar panels maybe important if the amounts of land between each household are limited.

5.2 – DESIGN ASSUMPTIONS

In designing the PV systems, certain assumptions were made for analyzing the cost of the whole system. Before making any assumptions, an appropriate location that is suitable for the PV system needs to be determined. According to the U.S energy information administration, the states of Arizona and New Mexico have the most sunlight per square meter (see Figure 23).

Figure 23. Federal lands with solar PV resource potential of 5 or greater [31]



Federal lands, lower 48 States, with solar photovoltaic resource potential of 5 or greater

Compared to other renewables, solar photovoltaic electric generation is dispersed and occurs in small amounts at each site. Currently, there is no inventory of solar photovoltaic facilities by location.

Ratings are in units of kWh per meter squared per day. Areas with ratings of 5 or higher have high potential for energy generation using solar photovoltaic technology

Source of solar photovoltaic resource potential measures:
U.S. DOE
National Renewable Energy Laboratory

From Figure 23, the team has decided to design PV systems to power a remote community of thirty households in the state of Arizona. There are certain assumptions being made for the designs which are shown below:

- The average amount of sunlight receive each day is about 10 hours
- The amount of radiation from the sun is 1000 W/m^2.
- There are discounts for buying solar panel in bulk quantities. One may receive a 5% discount for buying quantities of 50, a 15% discount for 500, and a 25% discount for 1000 solar panels. In addition, the discount cannot exceed 25%.
- There will be a small discount given for the individual case.
- Alternative designs would use the same equipment except for the solar panels.

In calculating the amount of electricity required for one household in one day, the energy for all the appliances that will be needed in the house are summed up.

Table 7. Estimated Use of Electricity in one day [22]

	Watts	Hours/ Day		Watts-hours/ Day	
Refrigerator/freezer	**500**	**x**	**24**	**=**	**12000**
Washing Machine	**600**	**x**	**0.25**	**=**	**150**
Drying Machine	**5000**	**x**	**0.25**	**=**	**1250**
Electric Stove	**1500**	**x**	**5**	**=**	**7500**
Microwave	**800**	**x**	**1**	**=**	**800**
Electric Oven	**1500**	**x**	**0.75**	**=**	**1125**
(2) 15W Lamp	**40**	**x**	**5**	**=**	**200**
Air conditioner	**1000**	**x**	**5**	**=**	**5000**
(4) Regular 20W Light Bulbs	**80**	**x**	**5**	**=**	**400**
Misc. Kitchen Appliances	**1500**	**x**	**0.25**	**=**	**375**
Computer	**300**	**x**	**5**	**=**	**1500**
Color Television	**300**	**x**	**8**	**=**	**2400**
Total watt-hours per day				**=**	**32,700**

Table 7 is a list of appliances and items that might be essential in one household. The energy is calculated by multiplying the power of each appliance with the estimated time they would be used in one day. The energy was totaled up to get the approximate total watt-hours for one household usage in one day.

5.3 – COST ANALYSES AND CALCULATIONS

5.3.1 – *Cost of Solar Panels*

From Table 7, the Equation 4 can relate the total amount of energy that is needed for a certain household, where H is the number of households and 32.7 kWh is the energy needed for one household.

Equation 4. Energy required for number of household/per day

$$E_{need} = H*32.7 \text{ kWh}$$

The energy produce by a single solar panel in one day can be related in the Equation 5, where P is the solar panel power and 10 hours is the amount of sunlight in one day.

Equation 5. Solar panel production per day

$$E_{panel} = P*10 \text{ hours}$$

The number of solar panels require to power certain amount of household in one day can be calculated by taking the energy needed divide by the energy produced by a single solar panel. This can be related by in the Equation 6, where SP_{need} is the number of solar panel needed, E_{need} is the energy needed to power a certain number of house, and E_{panel} is the energy generated by one solar panel in one day.

Equation 6. Number of solar panel required for certain number of house

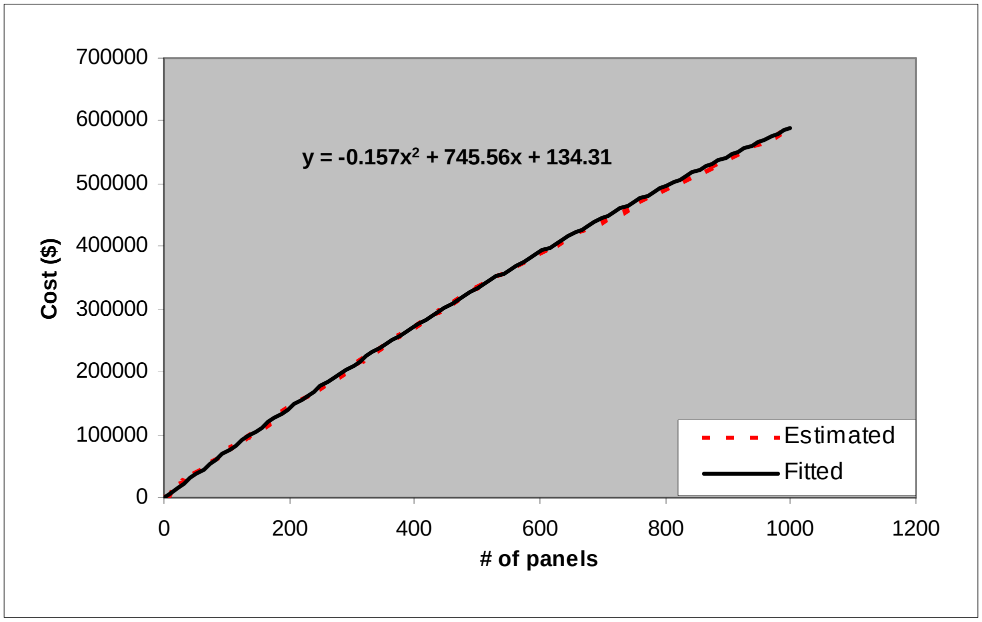
$$SP_{need} = E_{need} / E_{panel}$$

Substitute Equation 4 and 5 into Equation 6;

$$SP_{need} = (H*32.7 \text{ kWh}) / (P*10 \text{ hours})$$

Calculating the total cost for solar panels alone, a graph of cost versus the number of solar panels was created. Figure 24 is an example of total cost for solar panels versus the number of panels. The actual cost of buying solar panels with discounts was fitted with a polynomial function. The equation of the polynomial function was obtained using Microsoft Excel software (see Equation 7).

Figure 24. A sample model of cost buying solar panels



Equation 7. A sample model of the total cost for buying solar panels

$$y = - 0.157x^2 + 745.56x + 134.31$$

In the Equation 7, y represents the total cost of buying solar panels as the function of x, which represent the number of solar panel. By substituting Equation 6 into Equation 7, the equation for the total cost of solar panel is derived (see Equation 8).

Equation 8. Total cost for buying solar panels for BPS170XB solar panel

$$C_{total} = - 0.157*[(H*32700)/(P*10)]^2 + 745.56*[(H*24)/(P*10)] + 134.31$$

Equation 8 is for calculating the total cost for Bipolar BPSX170B solar panel, where H is the number of households and P is the solar panel power. The total cost can be calculated for providing any number of households. For example, if the solar farm consists of 30 households, the estimated cost for buying the solar panels is about $378,086. It is good to note that the polynomial function is different for different solar panels because of the cost per panel. Eight different brands of solar panels were compared in this design, which include Sharp, Kyocera, Shell, SunWize, Mitsubishi, Matrix, Bipolar, and General Electric.

5.3.2 – *Cost of installation, systems, equipment, and other costs*

The cost of installing the systems, equipments, and other costs were not taken into consideration in the previous calculation. The PV systems need batteries, inverters, charge controller, monitor, and transmission line.

5.3.2.1 – Cost of Battery

The PV systems need batteries, which are used to store the energy created by the solar panels. The power can be used when sunlight is not available. The batteries also are there to store excess power that solar panels are producing which is not needed at the moment. A 12 volt-inverter system and a Trojan Battery T105 (225 A.H.) model will be used. Each battery cost $89 each, and assumed that it only discharges 50 percent. The Equation 9 shows the relationship between wattage, voltage, and ampere.

Equation 9. Calculating the wattage [18]

$$\text{Watts} = \text{Volts}*\text{Amperes}$$

Since 32.7 kWh is needed for one household (see Table 4), the total number of amp-hours can be calculated base on Equation 10, where H is the number of household and 12 volts is the voltages that run through the household. The total energy was multiplied by 1.2 for due to the internal lost or efficiency of the inverter [22].

Equation 10. Total of Amp-Hour required for number of household per day [22]

$$A.H._{total} = (H*1.2*32.7\ \text{kWh})/12\text{volts}$$

The total number of battery is needed can be related in the Equation 11.

Equation 11. The number of batteries required

$$B_{need} = A.H._{total} / 112.5\ \text{amp-hr}$$

The total amps were divided into 112.5 because we assumed earlier that the batteries discharge is only half to maintain the battery longevity and maximum performance. By substituting Equation 10 into Equation 11, the total amount of batteries needed and its total cost for certain number of households is derived.

$$B_{need} = (H*1.2*32.7\ \text{kWh})/(12\text{volts}*112.5\ \text{A.H.})$$

Equation 12. Total cost of batteries for certain number of households

$$C_{battery} = (\$89*H*1.2*32.7\ \text{kWh})/(12\text{volts}*112.5\ \text{A.H.})$$

Equation 12 is the calculating the total cost of buying batteries, where H is the number of households and $89 is the cost of each battery.

5.3.2.2 – Cost of inverter

The energy produce by solar panels and batteries is in the form of direct current (DC). Common household appliances use alternating current (AC). The inverter changes the low DC voltage to high AC voltage in order to run common appliances. It was assumed that each household only needs one inverter. The model VFX2812 OutBack off-grid inverter is used and each costs $1,749 each. Equation 13 is for calculating the total cost of inverters, where H is the number of households.

Equation 13. Total cost of inverters for certain number of households

$$C_{inverter} = (H*\$1749)$$

5.3.2.3 – Cost of charge controller, monitor, and transmission line

Charge controller is a device that prevents the solar panels from overcharging the batteries. Batteries can hold a certain amount of power. The batteries can be damaged if more energy is put into them when they are full. The charge controller disconnects the solar panels when the batteries are full. Since all the batteries are connected in parallel to create a battery bank, one charge controller was needed.

The monitor displays everything that needs to know about the system, including the age-old question, "how much energy is left in the batteries?" Like the charge controller only one monitor is needed. The model Outback Mate2/RS232 Remote Monitor and Control is used and each costs $245.

The transmission line is needed to distribute the electricity to each household in the solar farm. There are two types of transmission lines, copper and aluminum. For the PV system, the aluminum transmission line was chosen over copper based on two advantages. The first advantage is that the weight of aluminum wire is 50% lighter than copper wire of the same size. Secondly, the diameter of the aluminum transmission line is larger than copper wire with the same resistance, which makes the aluminum line capable of carrying a larger current.

The XHHW-2 Aluminum conductor transmission line will be used in connecting the households to the solar farm. The size of the wire is 2AWG, which is capable of carrying 100 Amps of current, which is sufficient for the design. The cost of XHHW-2 Aluminum conductor is approximately $10.00 per foot. Since the solar farm will be about 400 feet away from the community, the line loss is negligible. Base on a distance of 400 feet, it requires $4,000 for the cost of the transmission line. For the individual case, transmission lines are not needed.

5.3.2.4 – Other costs

Another cost involves in solar energy technology setting up the PV systems. It is assumed that the community would hire 5 electricians to install the solar panels for the solar farm and 1 electrician is needed for individual case. Each electrician get pay $20/hour, work 8 hours a day, and take about two weeks to solar energy technology set up the solar farm and 3 days for individual case. The cost of installing a single household is about $480, while $11,200 for the solar farm.

5.3.3 – *Grand Total Cost*

The total cost is equal to the summation of all the costs that including buying solar panel, inverter, battery, controller, monitor, transmission line plus other costs. The State of Arizona offers a $1,000 tax credit for people who install PV systems on their homes. This is equivalent to a $1,000 off coupon on your state income tax. The United States government also offers a $2,000 tax credit for people who install solar electric systems on their homes. This is equivalent to a $2,000 off coupon on your federal income tax and can be carried over into future years until a total of $2,000 has been saved on taxes. This offer is good on systems completed between January 1, 2006 and December 31, 2007. [49]

$$C_{\text{farm}} = C_{\text{panel}} + C_{\text{battery}} + C_{\text{inverter}} + C_{\text{transmission line}} + C_{\text{installing}}$$

$$C_{\text{individual}} = C_{\text{panel}} + C_{\text{battery}} + C_{\text{inverter}} + C_{\text{installing}}$$

Equation 14. Grand total cost for solar farm PV system

$$C_{\text{grand total}} = C_{\text{farm or individual}} - C_{\text{state tax credit}} - C_{\text{federal tax credit}}$$

6. RESULTS

6.1 – PV SYSTEMS DESIGN TOTAL COST

6.1.1 – *Cost for Panel*

Equation 8 was used to graph the cost of buying solar panels as the function of the number of households. The total cost was based on the assumed discounts received for buying certain quantities of solar panels.

Figure 25. Total cost of solar panels vs. # of households

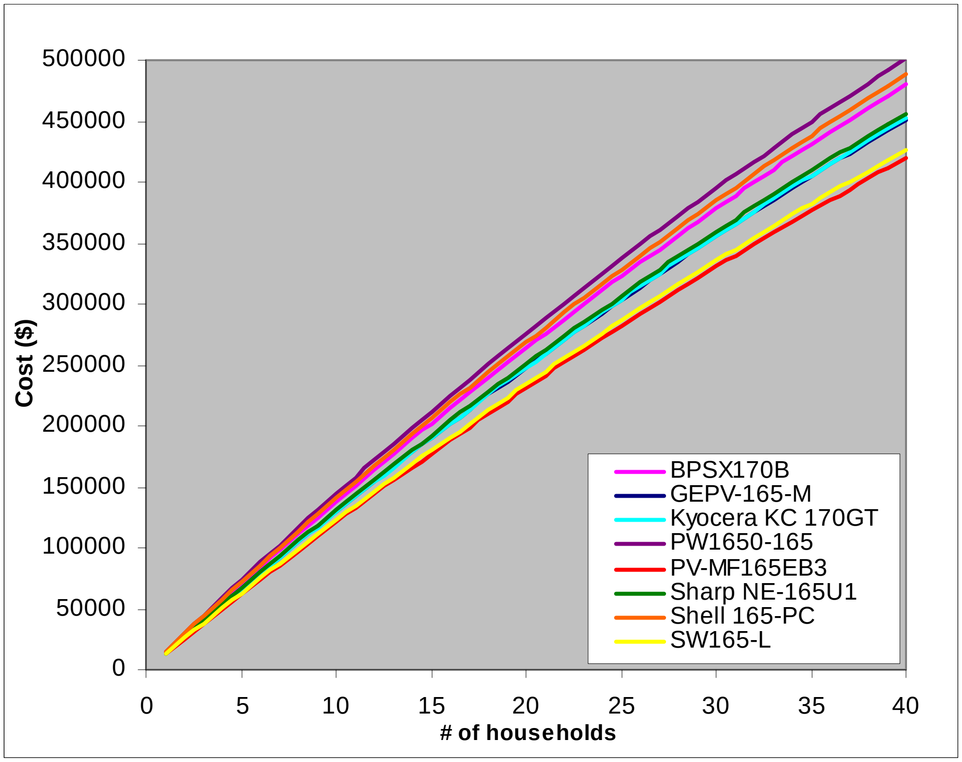


Figure 25 displays the relationship between the costs of buying solar panels for a certain number of households. Based on the graph, the total cost of solar panels can be determined base on the number of households in the community. In this design, the cost was focused on a community of 30 households both the solar farm and individual cases. The average power of the solar panels used to compare were 166.25W with a standard deviation of ± 2.3 W. The standard deviation is important when comparing the solar panels from each brand. If the standard deviation is too large, one type of solar panel will receive more discounts than the other, which need to be avoided.

Figure 26 is the magnification of Figure 25 for the total cost at 30 households. From observations, it clearly shows that the Mitsubishi PW1650-165 solar panel has the lowest cost for 30 households compared to other model brands.

Figure 26. Zoom in of total cost of solar panels vs. # of households

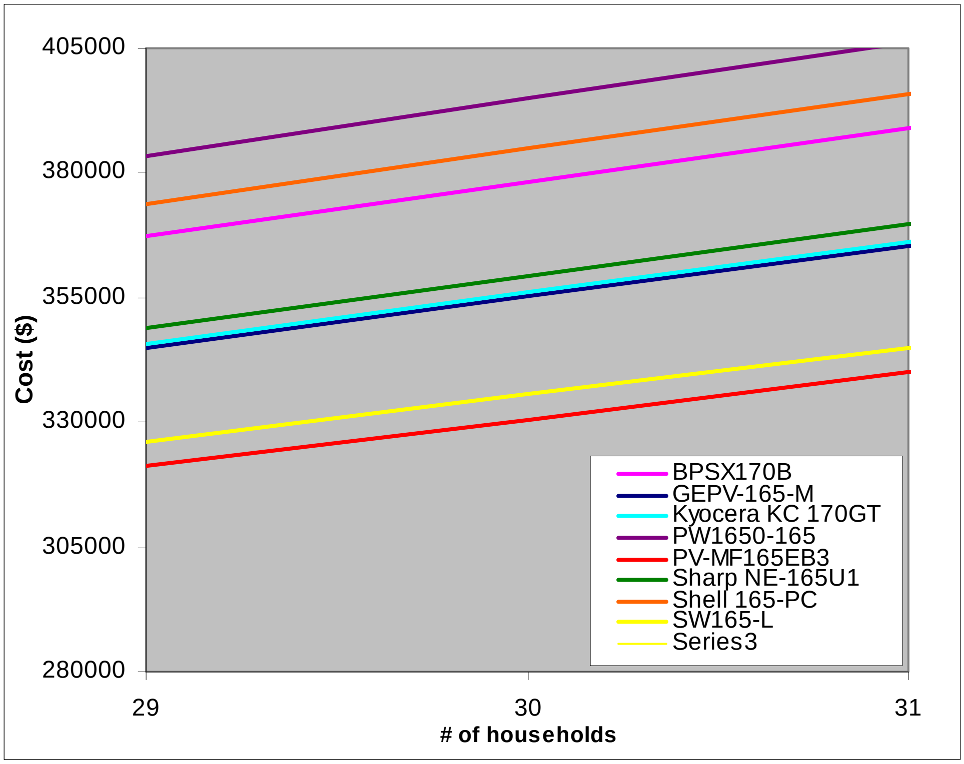


Table 8. Total Cost of Buying Solar Panels for 30 Households

Solar Panel Models	Cost ($) per Panel [7,8]	# Of Panel require	Cost w/o Discount	Cost Total ($) w/ Discount	Discount Received (%)
BPSX170B	785	577	452945	378086	16.5
GEPV-165-M	719	595	427805	355295	16.9
KC 170GT	739	577	426403	355930	16.5
PW1650-165	799	595	475405	394827	16.9
PV-MF165EB3	669	595	398055	330587	16.9
NT-165U1	727	595	432565	359385	16.9
Shell 165-PC	779	595	463505	384941	17.0
SW165-L	679	595	404005	335529	16.9

Table 9. Total Cost of Buying Solar Panels for Individual Household

Solar Panel Models	Cost ($) per Panel [7,8]	# Of Panel require	Cost w/o Discount	Cost Total ($) w/ Discount	Discount Received (%)
BPSX170B	785	19	15100	14417	4.5
GEPV-165-M	719	20	14249	13600	4.6
KC 170GT	739	19	14215	13572	4.5
PW1650-165	799	20	15835	15113	4.6
PV-MF165EB3	669	20	13258	12654	4.6
NT-165U1	727	20	14408	13751	4.6
Shell 165-PC	779	20	15438	14735	4.6
SW165-L	679	20	13457	12843	4.6

In tables 8 and 9, the total cost for solar panels without discount were calculated by multiplying the cost per panel with the number of panels required for 30 households and 1 household, respectively. The costs with discounts were calculated using Equation 8 by substituting in the number of households and the solar panel's power. The average discount received was 16.8 % for solar farm design and 4.5% for individual design and with a standard deviation of ± 0.2 % and ± 0.02%, respectively. In comparing the cost of panel, the discounts standard deviation need to be as low as possible because we do not want one solar panel to receive more discounts than the other solar panels when comparing the total cost. The discounts received for each panel model was determined using the Equation 15.

Equation 15. Discount received for buying solar panel in bulk

$$\% \text{ Receive} = [(C_{\text{no discount}} - C_{\text{discount}})/C_{\text{no discount}}]*100$$

6.1.2 – *Grand Total Cost*

Figure 27 displays the relationship between the grand total costs – includes the cost of buying solar panels, batteries, inverters, monitor, charge controller, transmission lines and installation – as a function of households. From on the graph, the grand total cost for each solar panel can be determined base the number of households in the community.

Figure 27. Grand total cost vs. # of households

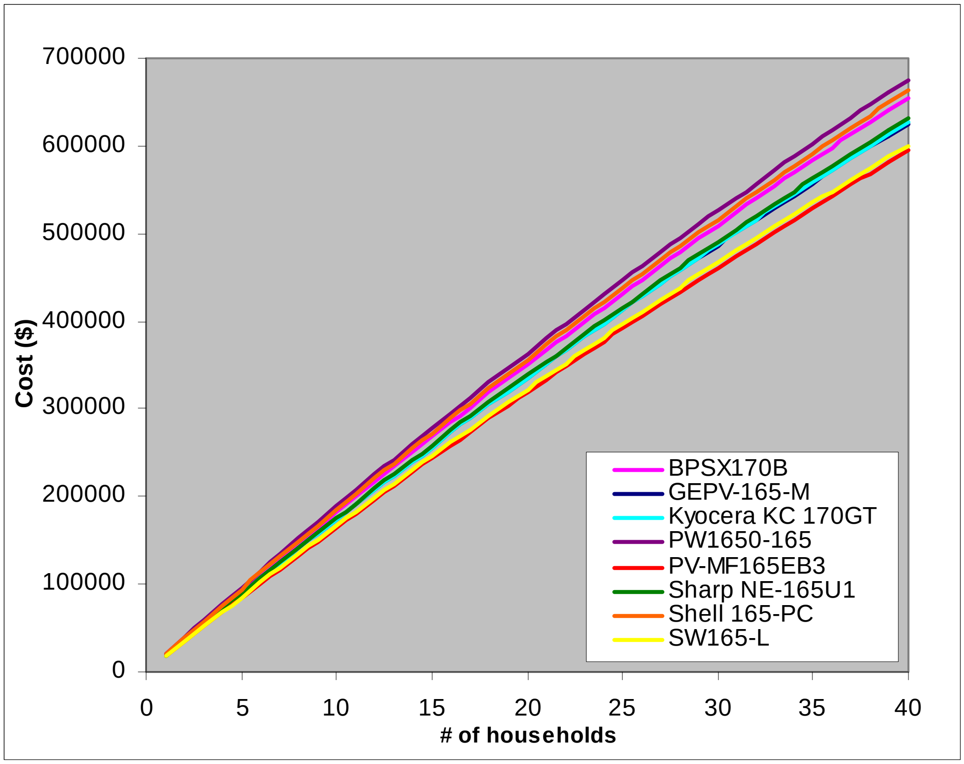


Figure 28. Zoom in of grand total cost vs. # of households

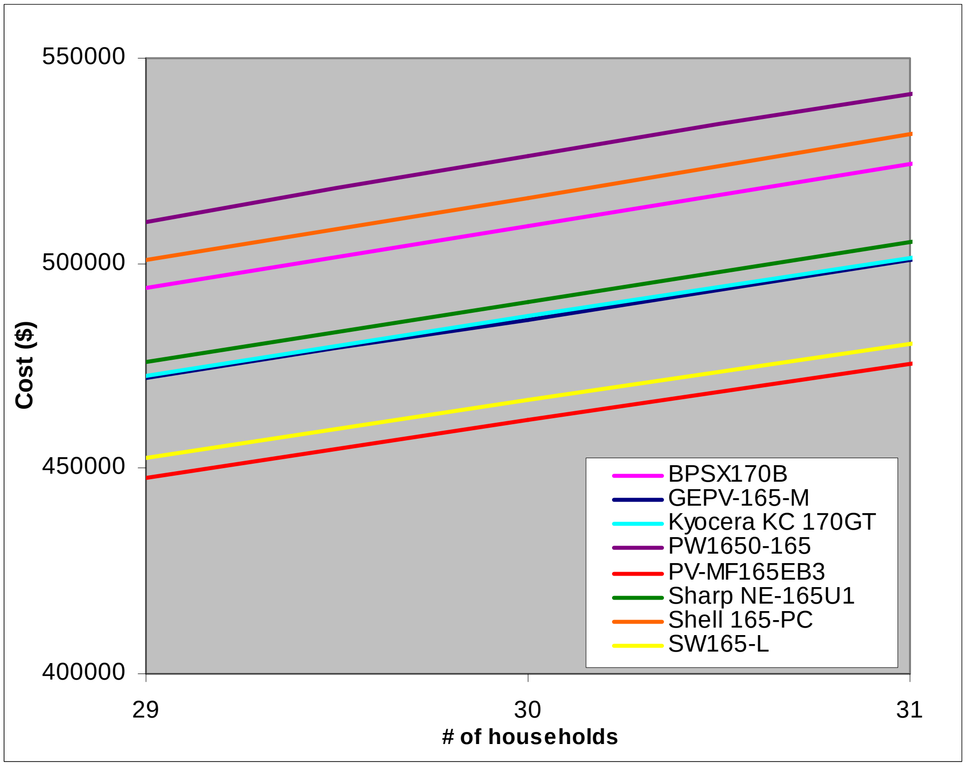


Figure 28 is the magnification of Figure 27 for the grand total cost at 30 households. From observations, it clearly shows that the Mitsubishi PW1650-165 solar panel still has the lowest cost for 30 households compared to other model brands.

Table 10. Grand Total Cost for 30 Households Solar Farm

Solar Models	Maximum Power (W)	Efficiency (%)	Longevity (year)	# of Panel Needed	Grand Total Cost ($)
BPSX170B	170	13.5	25	577	520364
GEPV-165-M	165	11.5	25	595	497573
KC 170GT	170	13.3	25	577	498208
PW1650-165	165	12.1	25	595	537105
PV-MF165EB3	165	13.1	25	595	472865
NT-165U1	165	12.7	25	595	501663
Shell 165-PC	165	12.5	25	595	527219
SW165-L	165	11.4	25	595	477807

Table 11. Grand Total Cost for Individual Household

Solar Models	Maximum Power (W)	Efficiency (%)	Longevity (year)	# of Panel Needed	Grand Total Cost ($)
BPSX170B	170	13.5	25	577	16233
GEPV-165-M	165	11.5	25	595	15416
KC 170GT	170	13.3	25	577	15388
PW1650-165	165	12.1	25	595	16929
PV-MF165EB3	165	13.1	25	595	14470
NT-165U1	165	12.7	25	595	15567
Shell 165-PC	165	12.5	25	595	16551
SW165-L	165	11.4	25	595	14659

In Tables 10 and 11, the efficiency of each solar panel model was calculated. The efficiency of the solar panel is considered to be important if the amount of land needed for installation is a constraint, which is for the individual case. The higher the efficiency of the solar panel, the less amount of land required to install it when comparing to other solar panels that have the same area and power. In this case, there will be a lot of land available in the rural area. So the efficiency of the solar panels was not as important as installing it in the metropolitan area. The solar panel efficiency was calculated using Equation 16, where P is the solar panel maximum power, A is the area of the panel, and 1000 W/m^2 is the amount of sun radiation.

Equation 16. Efficiency of solar panel

$$\text{Efficiency} = P/(A*1000W/m^2)$$

6.2 – FINAL DESIGN

Since the efficiency and longevity of the solar panel were not important factors in designing PV systems for this study, the solar panel that has the lowest grand total cost will be used. There are other miscellaneous equipments that are required for PV system were not taken into consideration such as cables for connecting the system together, AC/DC disconnect switch, and breakers which helps protect equipment from overloading. Equipment costs for the final design PV systems for the solar farm and individual case are listed below in Table 12.

Table 12. Total costs and the required components for final designs.

Cost and number of equipments required	Brands	Solar Farm	Individual Household
Cost	----------------------	$472,865	$14,470
Solar panels	PV-MF165EB3	595	20
Batteries	Trojan Battery T105 (225 A.H.)	650	29
Inverters	VFX2812 OutBack	30	1
Remote Monitor and Control	Outback Mate2/RS232	1	1
Transmission Lines	---------------------	400 ft.	-----------------

Figure 29. Outline of final design for a PV system for individual household

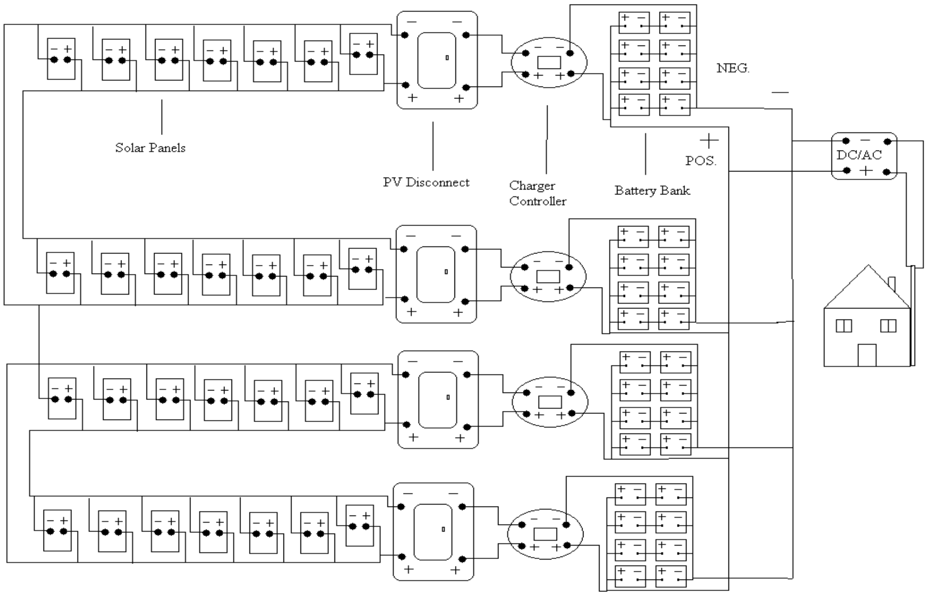


Figure 29 illustrates the entire outline of the final design of a PV system for the individual household. The solar arrays are connected to a charge controller to charge the batteries. Then batteries are connecting to an inverter, which converts DC current from the battery into AC current. The charge controller monitors the charging state of the batteries, and interrupts the current flow from the solar panels when the battery is fully charged. The DC disconnect Breaker is used to disconnect the solar array from the system in case of a maintenance check which is required every year. It is very important to be able to de-energize solar arrays from the electrical system.

Figure 30. Outline of final design for a PV system for solar farm

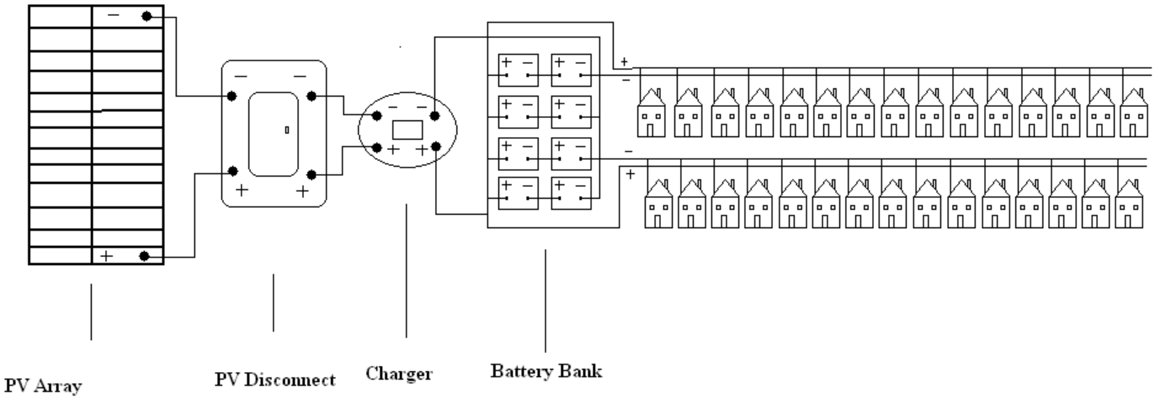


Figure 30 illustrates the entire outline of the final PV system design for the solar farm. The components are very similar to an individual household except that transmission lines are needed to transfer the electricity to the community.

7. DISCUSSION

7.1 – FINAL DESIGN

The estimated grand total price of the final design is not considered to be accurate due to the assumptions that were made. If the average amount of sunlight in one day were less than 10 hours, then more solar panels would be needed. This would increase the cost of buying solar panels. Also the assumption of 32.7 kWh of energy is needed for one day can be different depending on the appliances in each home, because not everyone uses or has the same appliances.

Another important factor that could affect the cost of the PV system is the amount of sunlight in the day. Throughout the whole year, there will be time when there is no sunlight available and also the amount of sunlight in the winter will be shorter compared to summertime.

The assumption of discounts received for buying a certain amount of bulk quantities may be too large in this design, because it reduced the cost of buying solar panels greatly for models required in great quantity. For example, a model with 100 W may require twice as much solar panel as using a model with 200 W but the total cost of buying solar panels of the 100W model maybe less than the 200 W model. For this reason, solar panels with the same or close power were chosen for this PV system design. Finally, the cost of transporting solar panels and other equipment to the community will also contribute to the final cost because they live in an isolated area.

7.2 – SUFFICIENT POWER

The final design of the PV systems is able to produce the minimum power for 30 households in the community. It is safe to have more power than it’s required to prevent power outage. Safety factor [20] is the PV system power divided by the minimum power required. The higher the safety factor, the likelihood of power outage is small. A safety factor of 2 was taken into consideration for the solar farm and for individual case. That would mean that the design would need twice as much solar panel than the original design. The PV system would produce twice as much power than the original. Also for the battery system, it is able to provide enough amps for just one day. A safety factor of

3 for the battery system is suitable just in case there is no sunlight three days in a row which would mean 3 times amount of batteries needed in the original design. This safety factor also covers the assumption of the amount of energy needed for one day since there is twice amounts energy is being produced.

8. CONCLUSIONS OF PV SYSTEM DESIGNS

8.1 – GENERAL CONCLUSION

The PV systems for solar farm and individual case using Mitsubishi PW1650-165 model has the lowest grand total cost compared to other solar panel brands. Other miscellaneous equipments such as breaker, cables, and disconnect switch, can be added to the final design. The grand total cost for building the solar farm and individual household estimated to be about $472,865 and $14,470, respectively. If safety factor is taken into consideration, the grand total cost was estimated to be about $1 million for the solar farm and $33,567 for individual case. The total cost of the solar farm PV system can be even larger then the estimated cost since the cost for buying solar panels exceeded 25%, which was assumed earlier. The grand total cost can be reduced if the town is able to install the PV systems instead of hiring electricians to do the job. Also the safety factor for the battery system can be reduced if the community or individual know how to conserve electricity if there is no sunlight available.

In comparison with using conventional energy, which costs roughly between $397,000 and $428,000, the PV systems cost more for the community with the safety factor taken into account.

Although solar energy does have great potential as a primary energy source, there are certain issues, aside from economic issues, that stand in the way of solar energy becoming a primary energy source. A minor issue is the visual impact that wide scale implementation will produce, which some may find unpleasant. A more serious issue is reliability of the technology. Since sunlight will not always be available, it will not be possible to achieve optimal energy output.

To compensate, the energy would need to be collected in great quantities in bursts and stored if not being used. The problem with this implementation is that, given current storage technology, a good deal of energy is lost while being stored and taken out of storage. The current storage technology is inefficient and also expensive. The potential of implementing solar energy as a primary energy source needs to wait for the advancement in storage technology as well as the efficiency of solar panels in order to be practicable.

There were some difficulties when designing the PV systems in this study. In order to overcome these difficulties, assumptions were made and this caused the estimated cost to be inaccurate. Certain recommendations for further study of this project need to have a better estimation of the power required for one household and include other equipments costs. It also recommended that finding the actual discounts for solar panels when buying them in bulk quantities would helps make the grand total costs of PV system more accurate.

9. INTENTIONAL COMMUNITY

An intentional community is a planned residential community with a much higher degree of social interaction than other communities. The purposes of intentional communities are varied. They may include sharing resources, creating family-oriented neighborhoods, and living ecologically sustainable lifestyles known as ecovillages. Some communities are secular, while others have a spiritual basis. Commonly there is a focus on egalitarian values. Other themes are voluntary simplicity, interpersonal growth and self-reliance. Some communities provide services to disadvantaged populations such as war refugees, homeless, or people with developmental disabilities [38].

Throughout history, there have been countless intentional communities made for many different reasons. Although many have not been entirely successful, they all give us perspective on how we should live; giving hope to those unsatisfied with the society they are in. Although other countries have had communal enterprises, they do not have voluntary collective communities as the kibbutzim had played in Israel. It’s importance to study the time period from Israeli state creation up until the present day. With a combination of socialism and Zionism, the kibbutzim were a unique Israeli experiment and were considered to be one of the largest communal movements in history. The kibbutzim were founded in a time when independent farming was not practical. They were forced by the necessity into communal life. Inspired by their own socialist ideology, the kibbutz members developed a pure communal mode of living that attracted interest from the entire world. While the kibbutzim lasted for several generations as utopian communities, most of today's kibbutzim are scarcely different from the capitalist enterprises and regular towns to which the kibbutzim were originally supposed to be alternatives [38]

An example of a religious intentional community is an Ashram. In ancient India, Ashram was a Hindu hermitage where sages lived in peace and tranquility with nature. These hermitage residents regularly performed spiritual and physical exercises, which include various forms of yoga. Many Ashrams also served as residential schools for children. Today, the term “ashram” is used to refer to an intentional community formed primarily for spiritual uplift of its members, often headed by a religious leader or mystic.

Solar energy may not have much to do with the goals of a Kibbutz or Ashram, but these communities can be viable options for implementing PV technology. Whatever motives for having these intentional communities, one important characteristic is the share of the living space between the people. Currently, communities like these exist around the world with the sole purpose of living as a community, with no other social, political, or religious motive. One such communities is Cohousing, which is an international initiative to build collaborative housing in which the residents actively participate in the design and operation of their own neighborhoods.

Cohousing residents are consciously committed to living as a community. The physical design encourages both social contact and individual space. Private homes contain all the features of conventional homes, but residents also have access to common facilities such as open space, courtyards, playgrounds, and common houses [40].

The Cohousing organization is a good practical model for the solar powered community. They build whole communities at once, so not only can they get the discounts that come with buying solar equipment in bulk, but also the price of the equipment can just be figured into the price of the house. These communities are also ideal for the proposed PV systems, because much of the maintenance can be performed by community participation, which in the case of Cohousing is a requirement for living in one of their communities.

If the community is more communal than the Cohousing organization and all funds are shared, similar to the kibbutzim, then half the work is done. Assuming the community has the money; they can purchase and install the PV systems.

Creating PV systems for intentional communities is also important for those intentional communities such as ecovillages, which care about the environment. Ecovillages strive to shift from high consumption lifestyles to more satisfying, high-quality, low environmental impact lifestyles and social structures [41]. Solar energy, which is more environmentally friendly than conventional energy sources, would make a good choice of energy source for such a community.

Another type of intentional community that has even less mandatory community involvement is a housing cooperative. A housing cooperative is a legal entity that owns real estate, one or more residential buildings. An Occupancy Agreement grants each shareholder in the legal entity the right to occupy one housing unit subject, which is similar to a lease. The Occupancy agreement specifies the co-op's rules.

As a legal entity, a co-op can contract with other companies or hire individuals to provide it with services, such as a maintenance contractor or a building manager. It can also hire employees, such as a manager or a caretaker, to deal with specific things that volunteers may prefer not to do or may not be good at doing, such as electrical maintenance. However, many housing cooperatives strive to run self-sufficiently (and recognize the economical efficiency of doing so), and its members complete as much of the community maintenance work as possible [38].

In such a community, the PV systems could help with their goal of self-sufficiency, and be economically feasible, not to mention being environmentally friendly. A co-op would most likely have the PV systems installed and maintained by hired professionals, with little cost to each individual.

It is the collective financial aspect of all intentional communities that makes them such ideal candidates for implementing PV systems that can compete with conventional energy. As prices for conventional energy rises and the prices for solar energy falls, this will only become truer as time goes on. Eventually, solar energy may become a viable energy source under any circumstances, especially if quantum dot solar technology ever becomes a reality. For now and in the near future, intentional communities and solar energy systems may be mutually beneficial to each other.

The benefits of the growth of PV technology are clear. Solar energy is renewable and environmentally friendly, and someday may be very cheap. The benefits of the growth of intentional communities may be a little less clear. Human beings are a communal species, and many people feel that the conventional living conditions do not cater to this.

There are organizations such as the Fellowship for Intentional Community (FIC), which comprised of intentional community groups that do not all share the same motives. Despite their differences, they seek out to motivate intentional communities, in which to be a superior way to live and on a step toward a utopian society.

10. REGULATIONS

10.1 – COMMUNITY ELECTRICITY USAGE POLICIES

After the PV systems are being installed into the community, policies of electricity usage in the community should be solar energy technology set up in order to gain maximum efficiency and preventing any possible blackout.

Every residence should be required to use Energy Star rated appliances. Energy Star rated appliances save almost 20% of energy usage compared to appliances that are not Energy Star rated. A good tip for saving electricity is using energy saving light bulbs. For conventional incandescent light bulbs, 90% of the energy is wasted through heat, and only 10% of the actual energy is used to produce the light. If every house needs a computer, it would be good to buy laptops instead of desktops, as laptops consume much less energy than desktop computers.

Every residence should be required to unplug any appliances that are not in use. The best way to do this is to use a multiple outlet with surge protection with an ON/OFF button. Simply press the ON/OFF button to turn off the appliance. Many modern electronic devices have capacitors inside their circuitry to help start the electronic devices quickly. For example, if a television is plugged into an outlet even without being turned on, it still takes electricity to keep its capacitor charged.

A community should keep updated with the weather forecast, since the solar electrical systems are solely dependant on energy from sunlight, and the battery banks only last about 2 days without sunlight. If cloudy or rainy weather persists for more than 3 days, it should definitely be required to reduce the amount of electricity usage. For example, if a community is notified about bad weather, they should avoid using electric entertainment systems in order to conserve electricity and avoid blackouts.

During hot summer days, every residence requires air conditioning. In order to save energy, air conditioning systems should be installed in living rooms or entertainment rooms where most family activities taken place. This will reduce the number of rooms that require air conditioning.

The solar panel system is valuable property of the community; any abuse or over-usage of the solar system should not be allowed. Such actions should be reported immediately to the proper community authorities.

10.2 – TIPS FOR CONSERVING ENERGY

The community may have to worry about blackouts. After all, solar energy is not 100 percent reliable, even with the help of storing excess energy in batteries. If the community wishes to avoid blackouts, there are products they could buy and habits they can form that will help alleviate this problem.

Among the biggest energy users in the average American household are air conditioners, electric heaters, electric water heaters, electric clothes washers and dryers, light bulbs, and refrigerators [26].

As far as refrigerators go, the most important thing to keep in mind is when it was made. Newer refrigerators use much less energy than older ones. Specifically, refrigerators built since 2001, when the American government limited the amount of electricity that refrigerators use per year to 500 kWh. Furthermore, as with the majority of home appliances, “Energy Star” qualified products use at least 10% - 40% less electricity than government regulations require [27]. In the case of refrigerators, energy star qualified models use 40% more than the 2001 regulation requires. That means modern energy star qualified refrigerators use only 300 kWh per year. The efficient models cost about $180 more than those that simply meet the 2001 regulation.

A simple way to save electricity used by light bulbs is to use compact fluorescent light bulbs. Compact fluorescent light bulbs put out as much light as regular incandescent bulbs, but last anywhere from 8 to 10 times longer, and use anywhere from 50 to 75 percent less electricity for the same light output [28]. A habit one can use to save electricity on lighting can be to simply turn light bulbs off when not using them. This rule applied to most home appliances as well. Using dimmer switches on your lighting fixtures also helps.

There is not much to be said about saving energy for laundry, other than the fact that one should wash full loads using cold water as much as possible, and use energy star qualified washers. Through superior design and system features, Energy Star qualified clothes washers that clean clothes use 50% less energy than standard washers. Energy Star does not rate dryers, as most all dryers use similar amounts of electricity. One should air dry clothes as often as possible to save electricity.

When our community heats their homes they should be sure to properly insulate them. The heating system that they use should be radiant, as radiant heat is more efficient than forced air. Other than that, only minor habitual modifications need be made. In the heating season, water vapors from bathing and cooking are beneficial because they help humidify the home. One should also use kitchen and bath exhaust fans sparingly in the winter to keep as much heat as possible inside the house [28]. All doors and windows should be left shut as often as possible as well.

Air conditioning is one of the worst users of electricity. About one-sixth of all the electricity generated in the US is used to air condition buildings. Energy Star rated air conditioners use only about ten percent less electricity than conventional models, so behavioral changes can make all the difference here. Keeping the temperature at seventy-eight degrees or as high as comfort permits will help. Also, cooling only one room at a time if possible will help save quite a bit. Insulating one's house properly and changing one's air conditioner's filter will also lower energy use.

11. SOCIAL ASPECTS OF COMMUNITY

A PV system may be ideal for beginning an electric lifestyle for a community in a developing country, where electricity may not be readily available. Life before solar PV energy technology would involve a simple lifestyle. For example there would be no electricity and electrical appliances would not be accessible. This would include candlelight, wood, and fire as resources for light and as well as resources for survival, as people used these materials and resources many years ago. People during this time period have to find ways to adapt to conditions such as the weather, seasonal conditions, and conditional specifications such as security that would be used to protect oneself or others during times such as bad weather and war.

There is also an Amish lifestyle. This would be a more reasonable lifestyle since Amish families and communities are still around today in the modern world. In addition, it would resemble a more modern lifestyle of a typical family household living with or without any electricity, where candlelight, wood, and coal would still be used.

In this study, two household cases are examined. One scenario is a single person household and another is a family, which involves parents and kids. The people's daily schedules in both scenarios are studied and then the differences before and after they have PV systems are compared.

11.1 – SINGLE PERSON WITH PV SYSTEM

In making a daily schedule for a single person in the household, certain assumptions were made

Assumptions:

- Assume that this scenario is as realistic as possible.
- The household consists of one person, whom is currently unmarried.
- The person works full-time and has a car.
- The salary varies for every person depending on his or her job. For purposes of this scenario, the salary would be reasonable enough to afford the solar energy technology even though the person's choice would be not to choose to live with the technology.

- The household location is located in a remote area.
- The person's lifestyle is fairly balanced
- The person has no electricity.

Using these assumptions, the schedule for a person would consist of the following:

Table 13. Weekday Daily Schedule for a person without PV system

	Time	Activities
AM session	10:30 – 6:30	Sleep (8 Hours)
	6:30 - 7:15	Wake up, Wash Up, eat Breakfast (*A)
	7:15-8:00	Drive to Work
	8:00-12:00	Work (Location and occupation is irrelevant)
PM session	12:00-5:00	Work
	5:00-5:45	Drive Back Home
	5:45-6:45	Make Dinner (*A)
	6:45-7:00	Shower
	7:00-9:00	House Chores and Recreational Activities (*B)
	9:00-9:15	Wash up
	9:15-10:30	Recreational Activities (*B)
	10:30	Sleep

Table 14. Weekend Daily Schedule for a person without PV system

	Time	Activities
AM session	12:00 – 10:00	Sleep
	10:00 - 10:15	Wake up and Wash up
	10:15 -11:00	Eat breakfast (*A)
PM Session	11:00 - 7:00	House Chores and Recreational (*B)
	7:00-8:00	Make Dinner (*A)
	8:00-8:15	Wash Up
	8:15-12:00	House Chores and Recreational or sleep

The following notes that refer to Tables 13 and 14:

- (*A) = Although there is no solar energy available, the person could still have a variety of foods. The only disadvantage is that there is no refrigerator for foods such as raw meat, eggs, and drinks.
- (*B) = Social events such as going out with friends and dating
    - If the person was married: the kids can be taken care of but schedule would be really busy.
    - The person can host parties but their friends would have to accept the lifestyle with no electricity.
    - The activities that would be entertaining would involve Amish entertainment such as Music that is of German Origin and Board Games. Dancing would be a possibility.

Tables 13 and 14 describe the scenario for a single household for weekdays and weekends without a PV system. On weekdays, the person wakes up and washes up and eats breakfast. The person works for 8 hours and comes back home. Note that 45 minutes is generally a long drive to the workplace. Most likely, the person would have to drive on highways, rather than having to drive exclusively on non-highway routes. The person comes home and does house chore work and makes preparations for the next day, which consist of washing up, dinner, and preparation for bed after a long hard working day. Note that in reality, any person living with and without solar energy would definitely be able to follow the schedule above. The only main difference would probably be in the eating habits and the luxury options since a person living with electricity and solar energy PV system would be able to do more things such as cook more foods and use electrical appliances.

Table 15. Weekday Daily Schedule for a person with PV system

	Time	**Activities**
AM Session	6:00 - 7:15	Wake up, wash up, and eat breakfast (A)
	7:15 - 8:00	Drive to work
	8:00 - 12:00	Work
PM Session	12:00 - 5:00	Work
	5:00 - 5:45	Drive to home
	5:45 - 7:15	Television, Dinner
	7:15 - 8:00	Video games
	8:00 - 10:00	Computer games and web surfing
	10:00 - 11:00	Dessert and Wash up
	11:00	Sleep

Table 16. Weekend Daily Schedule for a person with PV system

	Time	Activities
AM session	10:00 - 11:00	Dessert and Wash up, listen to music and IPOD
PM Session	11:00 - 1:00	Computer- Web Surfing, computer games
	1:00 - 5:00	Socialize, Parties
	5:00 - 6:00	Dinner
	6:00 - 7:00	Dishes and house chores
	7:00 - 9:00	Laundry and Chores
	9:00 - 12:00	Television and internet
AM	12:00 - 2:00	Movie
	2:00	Wash up and sleep

Tables 15 and 16 show a typical day for a person who lives with a PV system. The daily routines are similar in Tables 15 and 16 as opposed to Tables 13 and 14 in the sense that during weekdays, the person would get up, prepare for work, go to work, come home, make dinner, and then make the necessary preparations to go to sleep and prepare for tomorrow. The weekend is basically a rest period for the person. Socializing may be a possibility during weekends. Most teenagers today would socialize by going out with their friends during various times. There may be parties that are held over at some other people's houses. If the person had a PV system, then more food varieties such as meat, cooked vegetables, and other foods that require using a stove would increase food variety. The person also has an option of doing dishes with a dishwasher that could be installed at home. In addition, he or she can also watch the news or obtain the news by access to the Internet from a computer.

11.2 – FAMILY WITH PV SYSTEM

This scenario assumes that the person who is living with solar energy technology is married. The following assumptions would apply for a person of this lifestyle:

Assumptions:

- The household consists of a married person with 2 children (gender is irrelevant but age may vary).
- The person works full-time and has a car.

- The salary varies for every person depending on his or her job. For purposes of this scenario, the person must be able to afford solar energy and in addition must be about to support the kids.
- The household location is located in Africa.
- The person's lifestyle is fairly balanced (though this isn't the case for everybody), generally applies to everyone, and is living with no electricity.

Using the above assumptions the following schedules would resemble the following (both weekdays and weekends):

Table 17. Weekday Daily Schedule for family without PV system

	Time	Activities
AM session	10:30 – 6:30	Sleep (8 Hours)
	6:30 - 7:15	Wake up, Wash Up, eat Breakfast (*A)
	7:15-8:30	Drive to Work, Take children to school
	8:30-12:00	Work (Location and occupation is irrelevant)
PM session	12:00-6:00	Work, Pick up children from school
	6:00 -6:45	Drive Back Home
	6:45-7:45	Make Dinner (*A)
	7:45-8:15	Shower, Make food for children
	8:15 - 9:00	House Chores and Recreational Activities (*B)
	9:00-9:15	Wash up
	9:00 - 9:15	Recreational Activities (*B), take care of children, bedtime for children
	9:15	Sleep

Table 18. Weekend Daily Schedule for family without PV system

	Time	Activities
AM session	12:00 - 10:00	Sleep
	10:00 - 10:15	Wake up and Wash up
	10:15 -11:00	Eat breakfast (*A)
PM Session	11:00 – 7:00	House Chores and Recreational, lunch, take care of children (*B)
	7:00-8:00	Make Dinner (*A)
	8:00-8:15	Wash Up, take care of kids
	8:15-12:00	House Chores and Recreational or sleep

The following notes refer to Tables 17 and 18 schedules:

- (*A) = The information here is similar to the single lifestyle case with the parents exclusively. However, if children were involved, food varieties may vary with the children. More nutritious and reasonable foods would consist of dry cereal, cooked rice through fire and hot water. The best options may involve canned foods and fruit.

- (*B) = For a family household of four, there would be more variety of entertainment activities. For example, the parents could buy their children some board games, which may consist of modern games and exercises such as chess, checkers, “Sorry,” connect four, and chutes and ladders. There may be outdoor recreational activities and sports such as baseball with other friends, football, golf, and badminton.

Tables 17 and 18 show a typical daily schedules for a family living without PV system. Table 17 shows a weekday daily schedule for a family without a PV system. The parents wake up after sleeping for 8 hours. They make preparations for work and prepare food for children. The parents take the children to school. In either case, they are on their way to work. The children would take the bus home or if they stay in school for awhile, the parents would have to pick them up. The parents would come home and make preparations for the next weekday. On weekends, parents spend time with their children playing card games and watching television. House chores such as sweeping the floor, cleaning the bathroom, doing laundry, and doing dishes would be done during the weekend if they were not done during the weekday. Note that laundry would have to be done entirely by hand, which can be a tedious process since laundry machines must be operated by electricity. The kids would most likely play outside during the weekend.

For the daily schedule that corresponds to a household for weekdays and weekends, schedules resemble that of a scenario for the single person household. For the weekday, the schedule is obviously busier and more complex than the single person case since there are more people involved.

Table 19. Weekday Daily Schedule for family with PV system

	Time	Activities
AM session	10:00-6:00	Sleep
	6:00 - 7:15	Morning routine and make breakfasts
	7:15-7:30	Parents take children to school
AM and PM session	7:30 - 5:00	Drive to work and comeback to house whenever necessary.
	5:00 - 6:00	Make dinner
	6:00-7:00	Dishes and chores
	7:00-8:00	Television and News
	8:00 - 9:00	Spend time with kids
	9:00 - 10:00	Free Time
	10:00 - 10:30	Wash up and shower, and tuck Kids in bed
	10:30	Sleep

Table 20. Weekend Daily Schedule for family with PV system

	Timeline	Activity
AM session	10:00P - 10:00A	Sleep
	10:00 - 12:00	Breakfast, and lunch, and take care of kids
PM session	12:00 - 2:00	Relaxing
	2:00 - 4:00	Socializing
	4:00 - 5:00	Chores
	5:00 - 6:00	Dinner
	6:00 - 8:00	Recreational
	8:00 - 10:00	Relaxing
	10:00 - 12:00	Wash up
Midnight	12:00	Sleep

Tables 19 and 20 show a typical daily schedules for the weekend and weekday for a family that chooses to live a lifestyle in which a PV system. In the weekday schedule, the family makes preparations to go to and take their kids and then go to work. The family drives back home and performs a wide variety of activities such as cooking for the whole family, performing house chores such as dishes and cleaning, spending time with the kids, washing up, and tucking their children into the bed, and finally sleeping. During the weekend there are a wide variety of activities that the family performs, especially during the PM session. For example, the family can relax by playing board games, listening to music, or watching television. There may be socializing activities such as family or neighborhood gatherings. More or less, the weekend is a catch up day for any activities that were not done during the week.

If the person lives without electricity or any gas supply, the following may apply. There would be no candlelight, wood, or fire. There would be no electricity and television. There would be no stove, but if there were, it might be gas powered. People may be able to use cells phones but the cell phone would either require batteries or would require a remote-controlled battery charger that would be fairly expensive for mass production. There would be no refrigerator, which would mean no cold food or drinks in the summer. This problem may be temporarily resolved using ice but obviously, it would melt. One would have to wait for the winter to get the privilege but unfortunately, only occurs on a seasonal basis. Flashlights are also another addition to a source of light but batteries shouldn’t be wasted upon using these devices constantly but rather on a provisional basis and for emergencies.

The bottom line here for the case of a household family who undergoes the schedules listed above is certainly more hectic and busier than the single scenario case. For one thing, much more responsibilities are apparent for the household family case. The parents would have to ensure that their children is adapting to the technology. More importantly, they would have to make sure that their quality of life is more than sufficient. In other words, they would have to make sure that they are getting enough nutrition and moreover have a balanced lifestyle. In either scenario, the lifestyle for both families is definitely possible and is realistic if one were to actually go through the process of living with solar energy.

The scenarios involving life without PV systems are simpler than the scenarios involving life with PV systems but can be at a disadvantage as opposed to people living with PV systems. For example, people who live with PV systems have access to their own television and computer. They can get news by watching the television or by accessing the Internet where as for people who does not know the news since they live with no solar energy or electricity. For the people who do choose to live with PV systems, they may not get recent news until hours, days, or perhaps even weeks later. Although news can be obtained using a portable television that’s operated by batteries, money must be spent for the batteries since one set of batteries will not last forever. People with PV systems have to pay much more money for repairing and installing the technology as opposed to the people without PV systems. In addition, people who live with PV systems can get access to electrical appliances such as electrical stoves, dishwashers (which would eliminate the cleaning of dishes), lights, fans, phones, and cellular phone battery chargers (which would be used to charge cellular phones). In addition, again, people without PV systems installed at their homes are at a disadvantage, with regard to phones. For example, if another friend wants to come in contact with the person (living with solar energy), the person can help since he or she is a phone call away as opposed to the scenario (no solar energy), where people cannot be contacted by phone. In other words, communication processes are much more time consuming for people living without solar energy as opposed to people with solar energy.

12. PV TECHNOLOGY IN THE FUTURE

12.1 – QUANTUM DOT

A quantum dot is a semiconductor crystal whose size is in the order of just a few nanometers. It has been found that quantum dots produce as many as three electrons from one high-energy photon of sunlight. When today's PV solar cells absorb a photon of sunlight, the energy gets converted to at most one electron, and the rest is lost as heat. This could boost the efficiency from today's 20-30% to 65%. [13]

Quantum dots also have a versatile form. That is, because of the possibility of using liquid phase, and relatively low temperature processing it is possible to create junctions on inexpensive substrates such as coated glass, metal sheets etc. and dispense with the costly micro-fabrication processes used to make contemporary silicon and thin-film based solar cells. In other words, quantum dot solar equipment could potentially be made inexpensively compared to current solar PV technology. It is, however, in the research and development stages and will likely not be on the market for years to come, if at all.

12.2 – FUEL CELLS TECHNOLOGY

Swiss scientists discovered the principle of the fuel cell in 1838. A fuel cell is an electrochemical energy conversion device that is similar to a battery, but differing from a battery in that it is designed for continuous replenishment of the reactants consumed. It produces electricity from an external supply of fuel and oxygen. Common reactants used in a fuel cell are hydrogen on the anode side and oxygen on the cathode side. Usually, reactants flow in and reaction products flow out. Base on this principle, the continuous long-term operation is feasible as long as these flows are maintained.

Fuel cells are very useful as power sources in remote locations, such as rural locations and remote weather stations. Fuel cell systems do not store fuel in them, but rely on the external storage units; this technology can be successfully applied in large-scale energy storage. Take a rural area for example, the batteries would have to be largely oversized to meet the storage demand, but the fuel cells only need a larger storage unit. In the State of Washington, the Stuart Island Energy Initiative has built a complete system by which solar panels generate the current to run several electrolyzers whose hydrogen is stored in a large tank. The hydrogen is used to run hydrogen fuel cells that provide full electric back up to the residential site on this off the conventional grid.

12.3 – SPACE EXPLORATION

The applications of solar energy have great potential not only in the future of our planet, but also in the future of space travel and off-world colonization. Its applications in space are obvious, and are already being used to power satellites and unmanned space exploration probes. It is the only practical option under these circumstances, as it is impractical to recharge or refuel satellites by any other means and impossible in the case of probes. Since it costs a great deal of money to send these units into space, it is also practical to send the most state of the art, efficient, and by far the most expensive solar energy systems up with them, whereas on earth, the application of such systems is limited.

If/when humanity decides to colonize the moon; there is little doubt that solar energy systems will play a key role. This is especially true if quantum dot solar panels become a reality beforehand. Even if they were not, current solar PV panels would be a relatively cheap, reliable energy source for colonization of the moon, especially since many of the raw materials needed for solar panel production can be extracted on site. The costs of these systems, even using current technology would be a viable option simply because the other costs involved in moon colonization far surpass those of transport.

One of the few other feasible options for an energy source on the moon is a fusion reactor. Using a fusion reactor would work because Helium-3 which is required for a type of fusion reaction is abundant on the Moon. However, it's possible that reliable, efficient fusion reactors will not be available at the time of lunar colonization, which is why solar energy is a more likely candidate.

12.4 – GENERAL GROUP’S DISCUSSION

The current solar technology can be economically feasible, but it depends on the price of each PV module. If the price decreases as predicted on our price curve, then it will become more feasible in the future and many people will be able to afford solar panels. However PV technology is not able to solve the problem of our reliance on oil, since gas powered automobiles will continue to dominate the market for years to come. In year 1997, hybrid cars have been successfully developed and it is a growing market. We are expecting full electric cars in the future, and this will revolutionize the way we travel.

It is our assumption that the market for solar panels will grow greatly within the next century, but it will be a slow process that will have to wait for both technological advancement and social acceptance. Government programs can help with both of these issues by issuing subsidies and tax breaks for people who buy solar panels, and starting an advertising campaign to educate people about solar panel technology, thereby advancing the social acceptance of solar energy. In order for solar panels to become widely accepted, they will not only have to decrease in price, but increase in efficiency. Current solar panels with efficiencies around 20% will require a lot of space that may not be available in highly populated areas.

As our society is slowly weaned off conventional energy, a renewable energy source will have to take its place. It is out belief that solar energy will likely play a key role in this, since most other renewable energy sources have drawbacks such as limited scalability and dependence on special geographic conditions.

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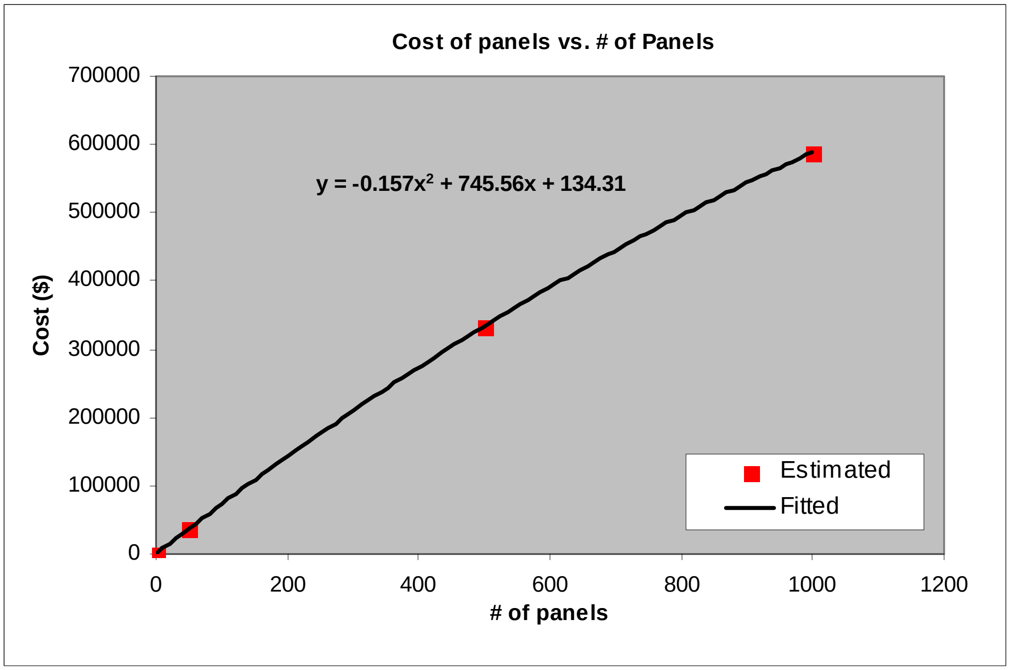
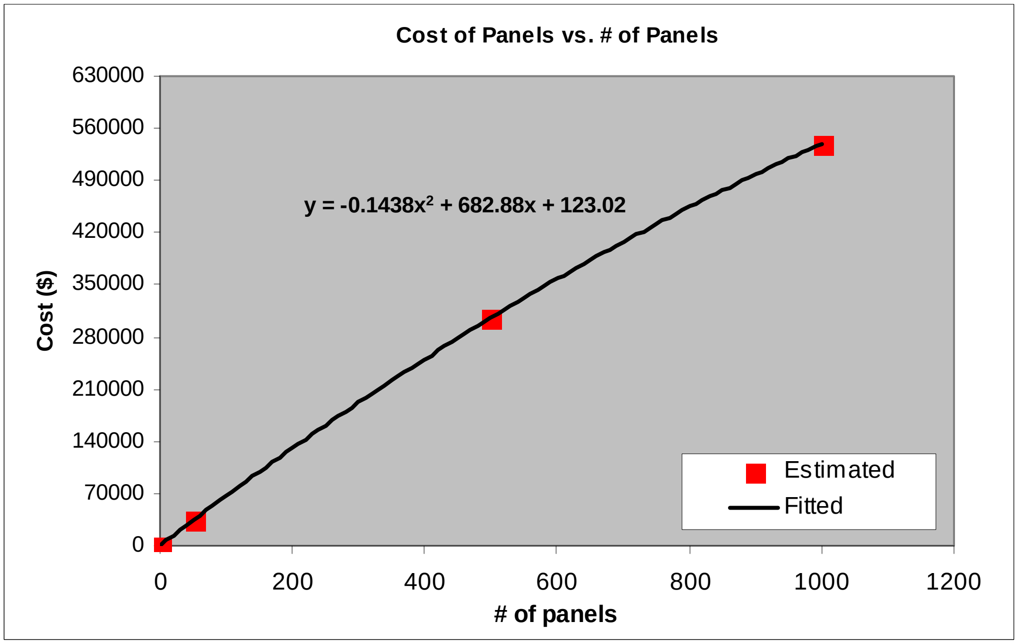
14. APPENDIX

14.1 – GRAPH OF COST OF PANEL VERSUS # OF PANEL

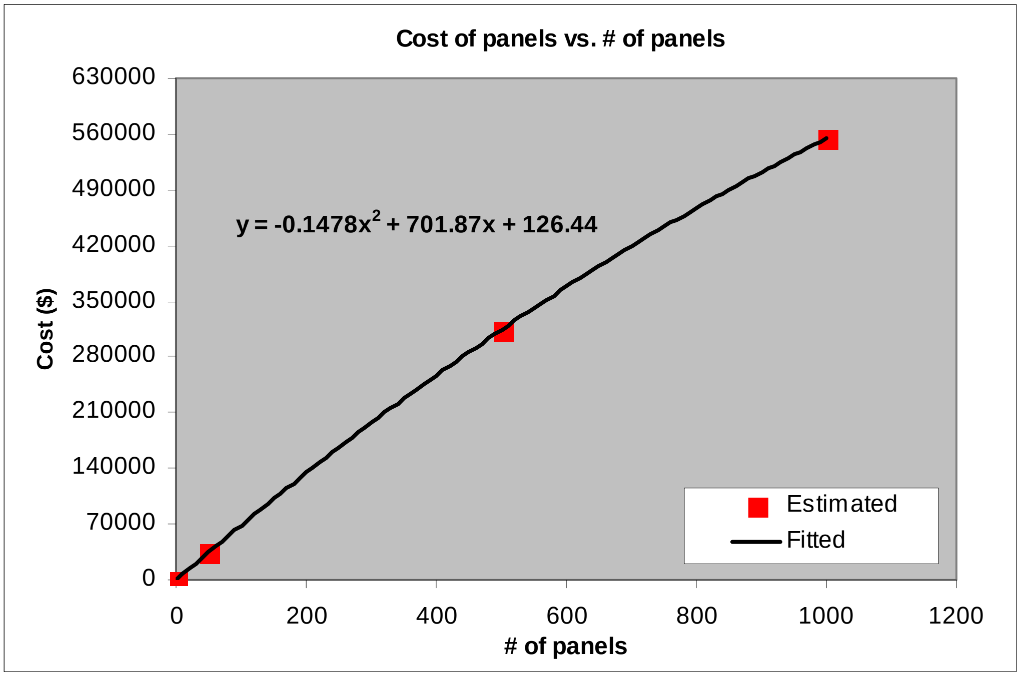
Bipolar model BPSX170B



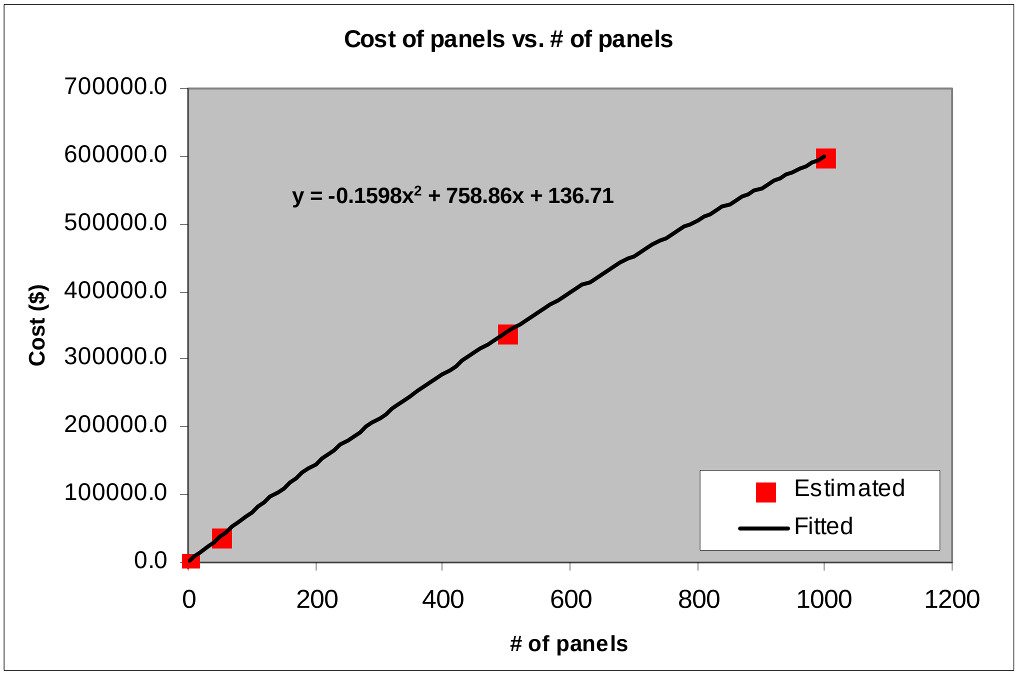
General Electric model GEPV-165-M



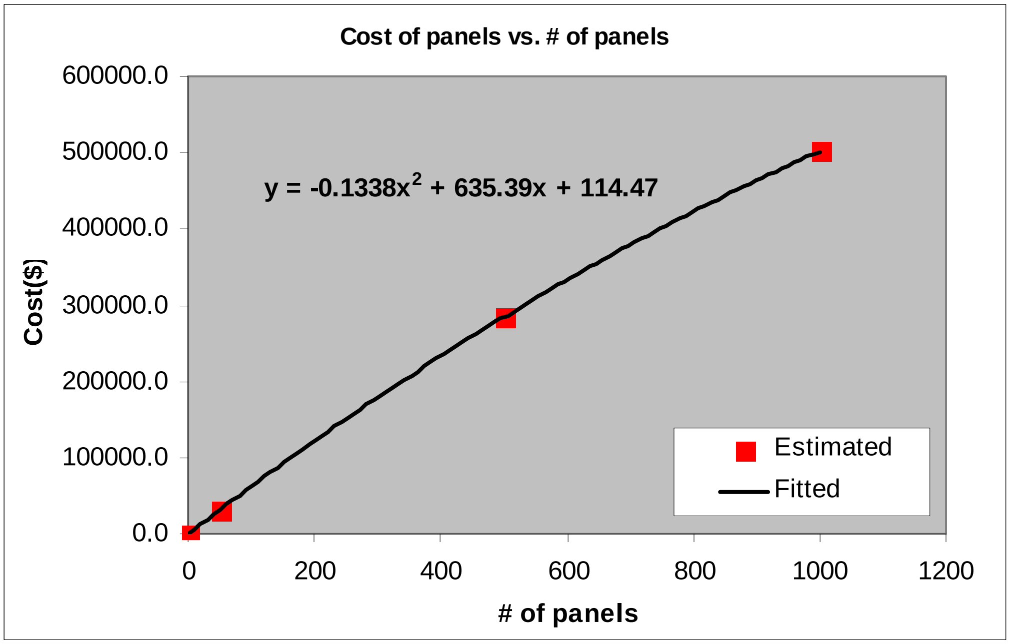
Kyocera model KC 190GT



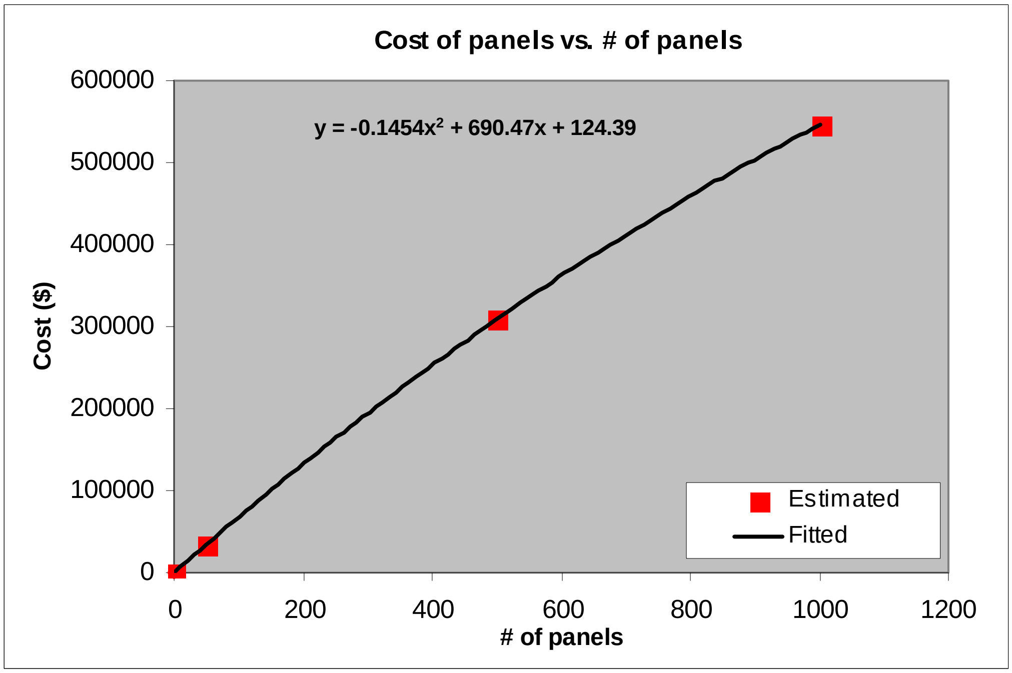
Matrix model PW1650-165



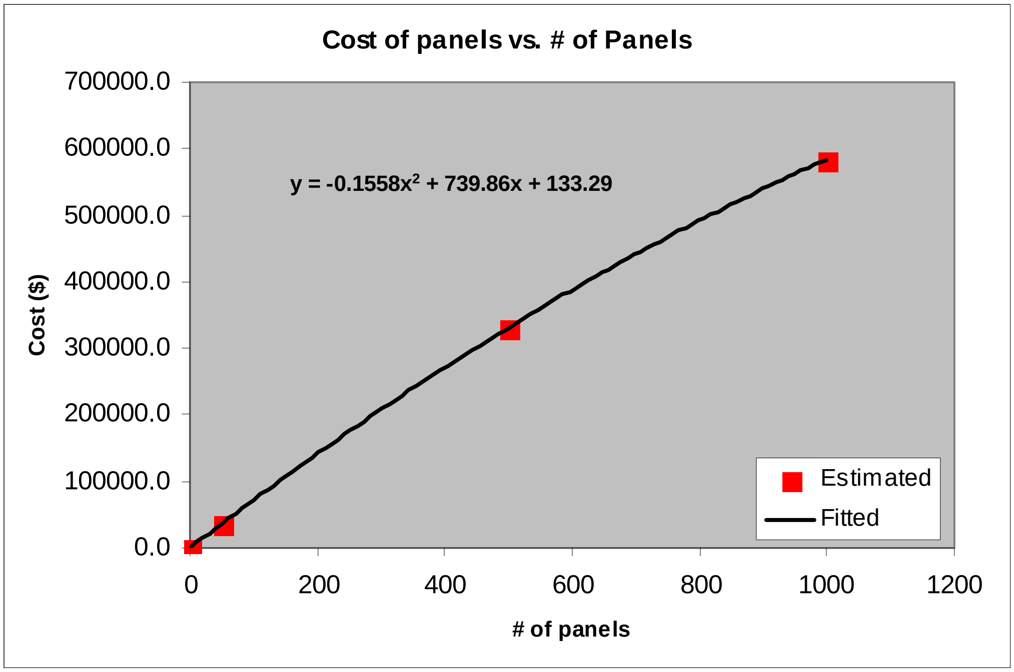
Mitsubishi model PV-MF165EB3



Sharp model NT-185U1



Shell model 175-PC



SunWize SW165-L